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EXPERIMENTAL TRANSMITTING AND RECEIVING EQUIPMENT FOR HIGH-SPEED FACSIMILE TRANSMISSION

II. DETAILS OF THE TRANSMITTER

621.397.61

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In the transmitter of the high-speed facsimile transmission system developed by Philips the documents to be transmitted are held electrostatically on a conveyor belt by a D.C. voltage of several kV. A rotating optical system, around which the conveyor belt is curved perpendicular to its direction of movement, scans the paper in parallel lines at the rate of 180 lines per second. The rotor comprises three identical scanning units set at angles of 120° to each other, so that it is only necessary for the conveyor to curve through 120° . The three scanning systems in turn project a scanning spot $\frac{1}{5}$ mm in diameter on the document to be scanned and at the same time concentrate the diffusely reflected light on a stationary secondary-emission photo-electric cell. A carefully designed optical system, using a film projection lamp as light-source, produces at the photo-electric cell a luminous flux of 0.20 for black and 0.70 millilumen for white parts of the document. As the signal supplied by the photo-electric cell when scanning white is 43 db above the noise level, the latter produces no visible fluctuations in the tone of the received image.

The performance of the facsimile transmission system evolved in the Philips Laboratories at Eindhoven may be outlined very briefly as follows. A continuous flow of drawings, photographs or other documents can be transmitted over a cable or radio link at the rate of 80 cm² per second (a sheet of quarto size in 8 seconds), details in the original as small as 0.2 mm being clearly reproduced. The receiver furnishes a reproduction which is reduced $6 \times$ in size, on a 45 mm film.

The function which this new facsimile system will fulfil as a complementary to the 60-times slower systems and other means of communication has already been reviewed in a previous issue ¹⁾. A more detailed description of the apparatus, comprising the mechanical and optical features of the transmitter, follows. The receiver will be dealt with in a similar way in another article, whilst the electrical circuits will be discussed in a later article to appear in this journal.

General arrangement of the transmitter

In accordance with the principle employed in every modern facsimile transmitter, the documents or images to be transmitted are scanned by a light-spot travelling across the page in successive parallel lines; the varying amount of reflected light is then converted by means of a photo-electric cell into a fluctuating electric voltage which is transmitted to the receiver.

In the usual slow facsimile systems scanning is effected by means of a rotating drum, around which the document is wrapped. An optical system is made to traverse slowly in a direction parallel to the axis of the drum in such a way that the scanning spot describes a helix of very fine pitch around the drum. Although this method is quite satisfactory in the slower facsimile systems, it is not suitable in a rapid system. In fact, placing a new document on the drum and restoring synchronism between receiver and transmitter for each transmission involves a loss of time of several seconds. When dealing with transmission times of only a few seconds this loss of time would affect efficiency to an intolerable extent.

It is true that in some systems the necessity of

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¹⁾ H. Rinia, D. Kleis and M. van Tol, Part I of this article: General Data, Philips Technical Review, 10, 225-231, 1948 (No. 8).

stopping the drum has been avoided, the "copy" being fed to it automatically. However satisfactorily this device may work at rotation speeds of about 3 revolutions per second, it would be impossible at 60 times that rate, which would be required by the short transmission time mentioned previously.

A new scanning method has therefore been devised in which the respective movements of the paper and the scanning device have been interchanged. The documents are thus fed continuously. *Fig. 1* illustrates the manner in which this is achieved.

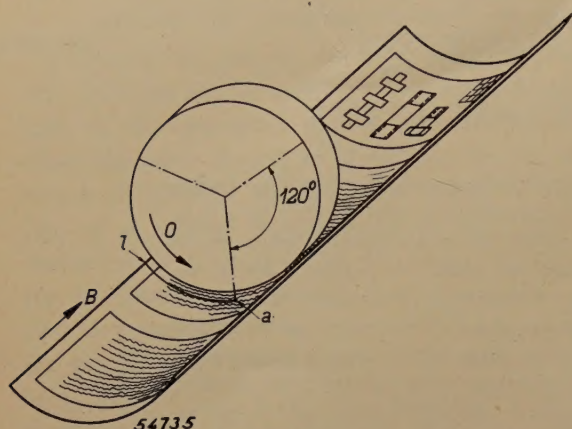


Fig. 1. A conveyor belt *B* with the documents upon it passes in front of a rapidly rotating scanning system *O*, the axis of rotation of which is parallel to the direction of travel of the belt, so that scanning takes place in the form of parallel lines. *l* represents one of these lines, with the scanning spot at the point *a*. The rotor embodies three optical systems set at 120° to each other, so that it is only necessary to curve the belt through 120° .

The copy to be transmitted is placed one sheet after another on an endless belt 22 cm in width. Subsequently the belt passes a rapidly rotating optical system which causes a scanning spot, 0.2 mm in diameter, to trace a line across the belt. Sharp definition of the spot is maintained by curving the belt at the point where scanning takes place, across its own direction of travel and around the same axis as that of the optical system. Since it is obviously not practicable to deform the belt to the extent of an entirely closed cylinder, it is curved only through 120° about its axis. The rotor comprises three identical optical systems set at 120° apart. The scanning spot of one of these scanning units traces its path across the belt in one-third of a revolution and is followed by the second spot, tracing the same path, during which time the belt moves on slightly, and so on. The belt and the rotor are coupled together by means of a reduction gearbox in such a way that the successive scanning lines on the paper — 0.2 mm in width — are exactly contiguous.

The desired curvature of the conveyor belt is produced by a cylinder, coaxial with the rotor (omitted for convenience in *fig. 1*), against which the advancing belt is thrust by a number of rollers. A slit in the wall of this cylinder permits the scanning light beam to pass through.

The manner in which the three scanning spots are obtained and the subsequent path of the light are illustrated in *fig. 2*. A stationary lamp is mounted in the geometrical axis of the rotor and three small condensers, arranged as an equilateral triangle around the axis of the unit, serve to concentrate the light rays onto three diaphragms. The three light beams admitted by the latter are then reflected in a radial direction from three flat mirrors into three objective lenses mounted in the periphery of the rotor. The foci are so calculated that the image of the light-source is reproduced by the condenser, in the aperture of each objective, whilst the latter — a microscope objective — focuses a reduced image of its associated diaphragm onto the paper.

The objective lens also serves to concentrate the light reflected from the illuminated spot on the paper (the reflected light of which is constantly varying in intensity during the scanning process), onto a stationary photo-electric cell mounted in the geometrical axis of the rotor. For this purpose an oblique mirror with central hole (*S*₁ in *fig. 2*) is located just in front of the objective; the light from the lamp passes through the hole in this mirror and floods the centre part of the objective. On the paper diffuse reflection of the light takes place and the reflected light floods the whole objective, a large portion of it falling on the mirror around the central hole. The mirror reflects this part of the beam, in a direction parallel to the rotor axis, onto a second mirror fixed to another rotor disc mounted on the rotor shaft. The latter mirror deflects the beam towards the centre of rotation, where a third mirror passes it to the photo-electric cell. The two last mentioned mirrors are also arranged in threes, each pair being set at 120° with respect to the others.

During the time that scanning spot *I* is passing over the conveyor belt, that is during $1/3$ of a revolution, the photo-electric cell receives light from optical system *I*; as soon as scanning spot *II* commences its path across the belt the cell receives light from system *II*, but this change-over will not be noticed by the photo-electric cell, provided the various systems are properly adjusted and the luminous intensities carefully balanced. The same applies to the change-over from system *II* to system

III, which follows one-third of a revolution later.

The shaft with the two rotor discs makes 60 revolutions per second, so that 180 lines are scanned in this time. This represents 1440 lines in 8 seconds, corresponding to a length of copy of 28.8 cm or roughly the length of a quarto sheet (21×29.7 cm).

The photo-electric cell is a multiplier type and, as will be shown later, the current produced in it under normal operating conditions, varying with the reflecting properties of the paper scanned, is about $70 \mu\text{A}$ for white. This current passes through a resistor, and the alternating voltage across it is amplified to about 25 V (peak), the resultant

The conveyor belt

After this brief review of the general design of the transmitter, details of some of the special features will now be given.

As long ago as 1928 Alexanderson endeavoured to realise the scanning principle which we have now adopted²⁾, but he employed a rotor with two scanning heads, necessitating a curvature of the copy through 180° at the scanning point. This deformation made it very difficult to keep the documents smooth while in motion and the mechanical methods adopted for this purpose were not very reliable.

The difficulty arising from the transportation of

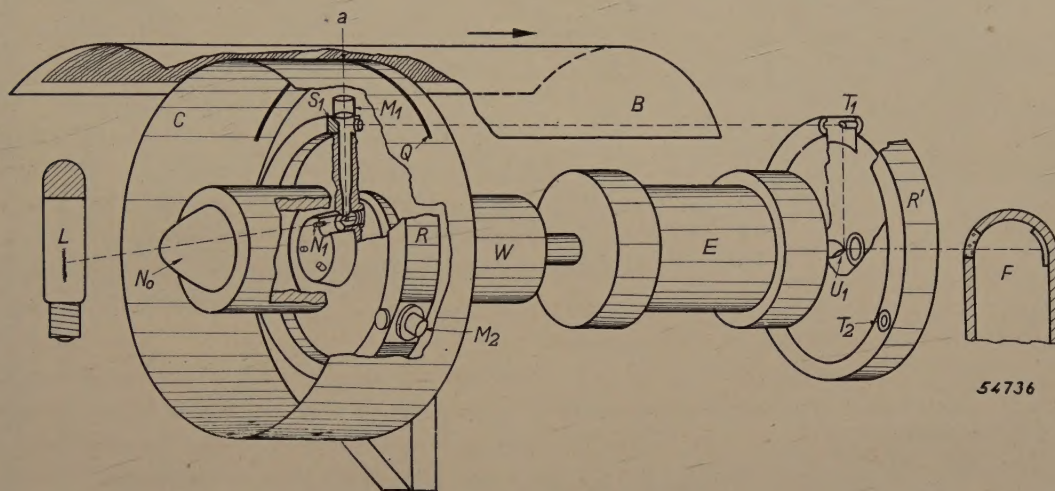


Fig. 2. The rotary scanning system, cut away to show some of the interior detail. The conveyor belt *B*, onto which the scanning spot (*a*) is projected, runs above the scanning system (not below it as shown for the sake of convenience in fig. 1). The documents are thus scanned from below, this arrangement presenting no difficulty in view of the method of adhesion employed, as described later.

C is a stationary cylinder, against which the belt is thrust; *Q* slot; *E* motor driving the rotor discs *R* and *R'*; *W* reduction gearing by means of which the slow travel of the belt is derived from the rotor drive.

The optical system, comprising a stationary lamp *L*, a stationary photo-electric cell *F*, an auxiliary condenser *N*₀ — which is not indispensable, but ensures a reduced (more concentrated) image of the lamp filament — and three sets of mirrors and lenses: the index 1 refers to the first of these; 2 refers to the second, whilst the third set is not visible in the sketch. *N*₁ condenser and behind it a diaphragm and mirror (not designated by letters); *S*₁ mirror with central hole; *M*₁ objective; *T*₁, *U*₁ mirrors.

signal being suitable, inter alia, for the modulation of the carrier wave of a radio transmitter. The electrical equipment must be capable of handling signals at frequencies of 0 to 100,000 c/s without attenuation, since on the one hand the constant average brightness of the copy (frequency 0) has to be reproduced in the receiver at the correct level, whilst on the other hand fluctuations in the luminosity up to 100,000 c/s must be transmitted in order to reproduce accurately details corresponding to the size of the scanning spot (0.2 mm).

the paper has now been overcome primarily by using three instead of two scanning units, which results in much less deformation of the paper, and secondly by applying a new electrical method of holding the paper firmly against the belt.

This method is based on the electrostatic attraction that occurs between the two electrodes of a capacitor. The belt itself is made from "Astralon", a

²⁾ See e.g. F. Schröter, *Handbuch der Bildtelegraphie und des Fernsehens*, Springer, Berlin 1932, p. 414.

member of the polyvinylchloride family of plastics³⁾ that has a high breakdown voltage and an unusually good surface resistance. The belt, 0.5 mm in thickness, functions as a dielectric between a per-

³⁾ "Astralon", known also as Igelit MP-A, is a mixed polymerisation product of 80% vinyl chloride, 10% dimethyl maleate and 10% diethyl maleate. It is employed as a substitute for celluloid, to which it bears a very close resemblance, although chemically entirely different.

manently earthed metallic layer on its inner side and the paper, which, although a very poor conductor, may nevertheless be regarded as a conductor for these purposes. The conveyor, with the documents on it, passes underneath and in close contact with an endless belt of brass gauze (see *fig. 3*) which is maintained at a high positive potential (7 to 10 kV) with respect to earth, by a simple high tension unit.

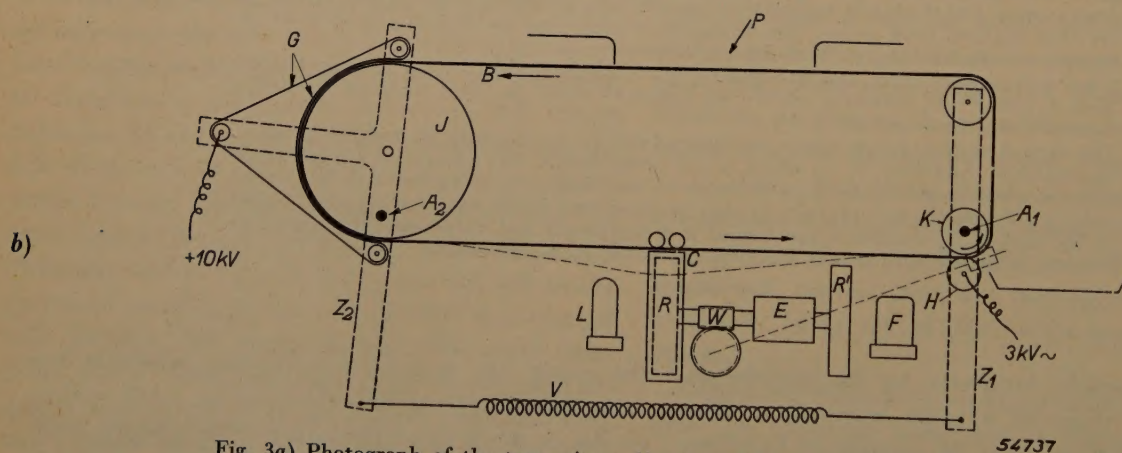
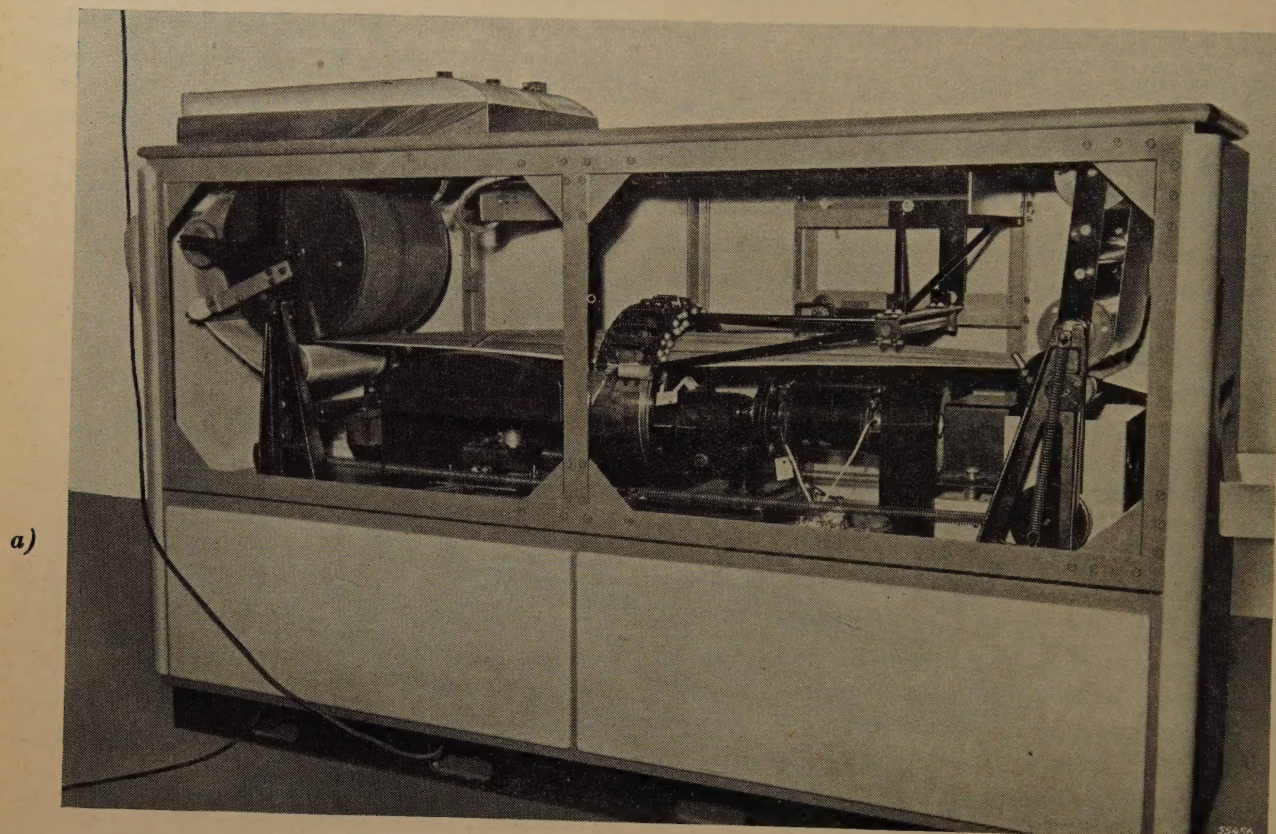


Fig. 3a) Photograph of the transmitter, b) schematic cross-section. The conveyor belt *B* is driven in the direction of the arrow by roller *K*. The documents are fed onto the belt at *P*. Passing over the drum *J*, the papers run between the belt (which is metallised and earthed on the inside) and a brass gauze belt *G*, maintained at a high potential with respect to earth. Due to the charge thus induced, the papers are held electrostatically to the belt. At *C* the belt curves round the scanning cylinder; the lateral curvature is clearly seen in the photograph (*a*). The documents are discharged by roller *H*, which carries a high alternating voltage; at this point they are therefore released from the belt and drop into a collecting tray. The drum *J* and all the rollers over which the belt runs are carried on two rockers *Z*₁ and *Z*₂ which are pivoted at *A*₁ and *A*₂; a spring *V* holds the belt taut, thus ensuring uniform movement of the latter at the scanning point. *E* motor driving *R* and *R'* and, through reduction gears *W*, the roller *K*. *L* lamp. *F* photo-electric cell.

During the period (approx. 15 seconds) that the paper is in contact with the brass belt an electrical charge is gradually built up in the paper and on the "Astralon" belt and is retained during the necessary travel of the latter. The paper thus adheres firmly to the belt, so much so, in fact, that a force of 0.5 kg/dm² would be required to detach it tangentially. The insulation properties of the paper (in not too humid an atmosphere) are sufficient to prevent the charge from leaking away prematurely towards the earthed scanning cylinder; even the short contact with the latter produces no appreciable discharge.

After passing the scanning cylinder the belt runs between a metal roller *H* and a driver roller *K* which carries the belt along by friction, without slip. Roller *H* carries an alternating voltage of about 3 kV, derived from the high tension unit already referred to and which discharges the capacitor formed by the "Astralon" with its metallisation and the paper document. Once the capacitor has been discharged, the paper drops off the belt at a point beyond *H* into a collecting tray ⁴⁾.

Another great advantage of this fixing method is that the documents are not limited to any particular size; they may be of any length and up to any width not exceeding the width of the conveyor belt itself.

In the process of feeding the documents onto the belt it is possible that the hands may touch it and tend to slow it down. In order to prevent this from producing irregularities in the movement of the belt along the scanning head, all the rollers over which the belt passes are carried by a pair of rockers, pivoted on shafts *A*₁ and *A*₂ (fig. 3*b*), the belt being kept taut by a spring between the lower ends of these rockers. If the belt should be retarded at a point *P*, the roller *K* can nevertheless continue to pull the belt over a short distance; the extra belt length is ensured by the fact that the left-hand rocker makes a slight clockwise movement. The spring also pulls over the right-hand rocker in the same direction, the part of the belt which is moving towards that side thus remaining taut in spite of the

braking effect at *P*. Since the pivot *A*₁ is also the shaft of the driving roller *K*, the latter, however, will retain its position. Consequently the length of belt between the driving roller and the fixed point *C* where scanning takes place remains constant and, provided that the retardation is not of long duration, the movement of the belt at *C* remains practically unaffected by the movements of the rockers.

It will be seen that this simple form of compensation is made possible only by the fact that the documents are fed in and scanned at opposite sides of the belt; in other words the documents are scanned whilst they are "suspended". This again illustrates the importance of the very efficient adhesion of the documents on the belt.

The scanning system

The path of the light through one of the scanning units is illustrated diagrammatically in fig. 4. In order to ensure a reasonable luminous flux at the photo-electric cell, notwithstanding the small size of the scanning spot of which the reflected light is picked up and in spite of the considerable losses incurred in the complicated path of the light beam, it is essential to employ a luminous source of great brightness and an objective of very high f. number (numerical aperture). The light-source is a projector lamp of 400 W, 110 V, with highly concentrated filament, giving a brightness of 2270 candles/cm² (average of the whole area of the filament). A microscope objective of numerical aperture 0.3 is used for projecting the image. The focal distance of the objective is such that, with the sum of object- and image-distance amounting roughly to the radius of curvature of the paper (as governed by the width of the belt), an image of the diaphragm, reduced 4.5 times, is produced on the paper. In view of the required width of 0.2 mm for the scanning spot, the diameter of the diaphragm is thus 0.9 mm, this being a convenient size for manufacture and adjustment.

The objective *M* serves to concentrate both the incident and the emergent rays. The size of the hole in the mirror (*S*, fig. 4) determines what part of the objective aperture will be available for each of these two functions; there will obviously be an optimum size for the hole. Let the diameter of the objective be *D* and that of the hole *d*; the total aperture is then $A \sim D$, the effective part for the incident light is $A_1 = A \cdot d/D$ and the part for the returning beam $A_2 = \sqrt{A^2 - A_1^2} = A \sqrt{D^2 - d^2}/D$. The luminous flux received by the photo-electric cell is proportional to $A_1^2 \cdot A_2^2$, that is $\sim d^2 (D^2 - d^2)$, which assumes a maximum at $d^2 = D^2 - d^2$, i.e. $d = \frac{1}{2} D \sqrt{2}$. The hole in the mirror must there-

⁴⁾ This method of discharging, whereby every point of the conveyor belt is successively exposed to an alternating voltage the amplitude of which upon approaching and leaving the roller *H* subsequently increases from 0 to 4 kV and then decreases back to zero, is somewhat analogous to the well-known manner of demagnetisation of a magnet by means of a decaying alternating current. In this case it is the charged condition of the "Astralon" which is annihilated by the alternating field. It may be noted that the process of "charging" the paper and belt is actually rather more complicated than would appear from this very brief description. Very thin layers of air between the paper and the belt play a very important part, in that they induce a "charge pattern" on the "Astralon" which appears to a great extent responsible for the very considerable adhesion.

fore roughly be 0.7 times the aperture of the objective; the effective numerical aperture of the latter for each of the two functions is thus $A_1 = A_2 = 0.7 A = 0.21$. (If the reflection from the paper is more or less specular instead of purely diffused, better results are obtained if A_2 is slightly greater than A_1 .)

In principle it would be possible to employ a microscope objective having a higher numerical aperture than 0.3, but this has not been done for two reasons: in the first place, with a larger aperture the "image distance", that is the distance from the paper to the face of the objective, between which

fact that both the light-source and the photoelectric cell had to be located stationary in the geometrical axis of the rotor, so that they had to be mounted on either side of the motor and reduction gear-box. The aforementioned lenses also seal the cavities in the discs and tend to keep the mirrors etc. free from dust. These discs, rotating at 3600 r.p.m., act in much the same way as a vacuum-cleaner, so that, without obturation, the light received at the photoelectric cell would soon be reduced too much by contamination of the mirrors and lenses.

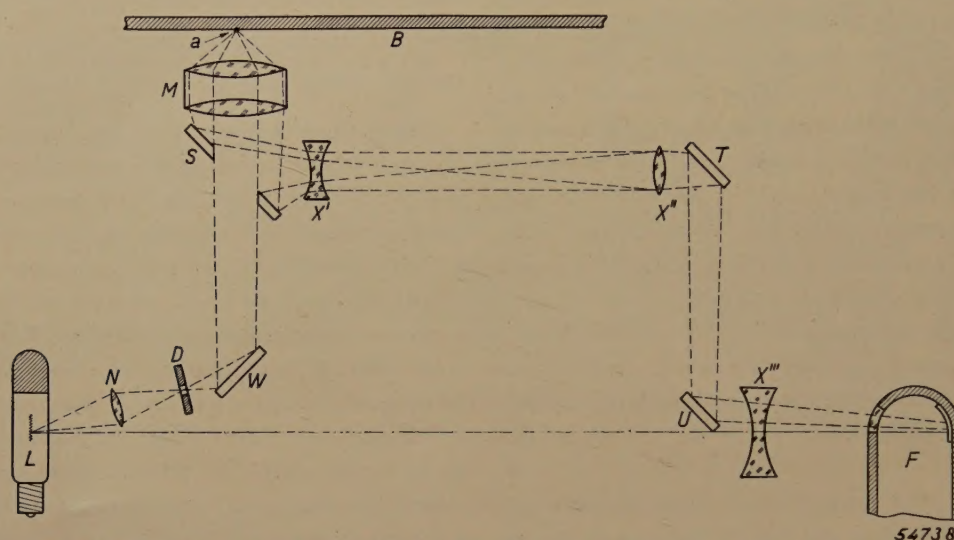


Fig. 4. Path of the light beam in one of the three optical systems in the rotor. *L* lamp; *N* condenser (the auxiliary condenser N_0 in fig. 2 is now not shown). *D* diaphragm; *W* mirror; *S* mirror; *M* microscope objective; *a* scanning spot on the conveyor belt *B*; *T* and *U* mirrors; *F* photo-electric cell. X' , X'' , X''' lenses to focus the rays and ensure that these are fully received by the mirrors and the photo-electric cell.

the fixed cylinder with its scanning slot has to be mounted, would be rather too small. Secondly, the depth of focus would be reduced. A certain amount of depth of focus is essential in view of the necessary tolerances in the focusing, possible slight eccentricity of the rotor with respect to the cylinder supporting the moving belt, possible vibrations of both these components, or small irregularities in the paper adhering to the belt. Should the distance vary for any of these reasons to the extent of + or - 0.1 mm, the diameter of the scanning spot would increase from 0.2 mm to $0.2 + (2 \times 0.1 \times 0.21) \approx 0.24$ mm at a numerical aperture $A_1 = 0.21$, which may be regarded as permissible.

From fig. 4 it will be seen that the light deflected by mirror *S* passes through three more lenses; these prevent any spreading of the beam, thus ensuring that it will be entirely intercepted by the mirrors in the rotor and by the photoelectric cell. The relatively great distance between the two rotor discs, necessitating this precaution, is due to the

Let us now approximately calculate the luminous flux Φ received by the photo-electric cell. Let *B* be the average brightness of the filament of the lamp and *F* the area of the scanning spot: the luminous flux falling upon that area — ignoring losses in the optical system — is then:

$$\Phi_1 = \pi B F A_1^2.$$

We will assume that the reflection from the paper is wholly diffuse, the reflection factor being r_w at the whitest parts and r_z at the darkest (e.g. those covered by printing ink). Of the luminous flux $r_w \Phi_1$ emitted by the white paper within a solid angle of 2π , the objective area available for the return beam receives the fraction $r_w \Phi_1 A_2^2$. If *q* be the factor by which the light is attenuated due to reflection losses in the optical system, the ultimate luminous flux at the photo-electric cell when white paper is being scanned is given by:

$$\Phi_w = \pi q r_w B F A_1^2 A_2^2.$$

As the light from the lamp has to pass through a total of 20 glass-to-air interfaces in its path to the photoelectric cell, each time with a loss of 4% due to reflection, and is further reflected 4 times at a (metallic) specular surface at an angle of 45° , each time with a loss of 20% due to absorption, q may be calculated to have a value of $0.96^{20} \times 0.80^4 \approx 0.18$. The reflection factor r_w of white paper may be put at 0.85 and that of the blackened parts at about 0.25. Putting: $A_2 = A_1 = 0.21$, $B = 2270$ candles/cm² and $F = \pi(0.01)^2$ sq.cm, the luminous flux will be $\Phi_w \approx 0.70$ millilumens. Scanning of the black portions similarly gives $\Phi_z = \Phi_w r_z/r_w \approx 0.20$ millilumens.

The photo-electric cell; the signal

By means of a secondary-emission photo-electric cell the very small available luminous flux can be made to deliver a signal of adequate strength relative to the unavoidable "noise" interference; an ordinary photo-electric cell would not be capable of this, as will be explained below.

A standard photo-electric cell of the vacuum type delivers roughly 20 μ A per lumen. At the values of luminous flux mentioned above, currents of between 4×10^{-9} and 14×10^{-9} A would have to be handled. In practice, a reduction in the sensitivity of a photo-electric cell in course of time has to be allowed for, whilst the luminous flux itself will also tend to decrease owing to gradual blackening of the projector lamp bulb and accumulations of small quantities of dust etc. on the numerous surfaces of the optical system. Allowing for a suitable safety factor, the operating current should therefore have a value which is a factor of 10 lower, that is between 4×10^{-10} and 14×10^{-10} A for black and white respectively.

By including a resistor $R = 10,000 \Omega$ in series with the photo-electric cell a signal voltage varying between 4 and 14 μ V is available for feeding to the input of an amplifier. A noise voltage occurs in the resistor in question the magnitude of which, according to a well-known formula, is expressed as $\sqrt{4kTR\Delta f}$, where k is the Boltzmann constant, T the absolute temperature and Δf the effective frequency band employed. Since we have to take a value as high as 100 kc/s for Δf (see above), the noise voltage in the resistor will be 4 μ V. In the case of the black parts of the document we therefore have a noise signal of the same order as the signal strength desired and this (assuming that the reproduction of half-tones is required) would be intolerable. The position might be improved by using a resistor of a higher value, as the signal increases in

direct proportion to R and the noise only in proportion to $\sqrt{R}$. If R is much higher than the above-mentioned value of 10,000 Ω , frequencies in the region of 100 kc/s in the photo-current would, however, be severely attenuated on account of the unavoidable capacitances in parallel with R (e.g. the input capacitance of the first amplifier valve).

The use of a secondary-emission cell greatly improves the situation. Owing to the internal gain in the successive secondary-emission stages very much higher photo-currents are produced; a tube developed by Philips, containing 8 stages and employed in the facsimile transmitter under review, yields a current of 1 A/lumen⁵). For the same resistor in series with the photo-electric cell, and again allowing a factor of safety of 10 for ageing of the tube, reduction of luminous flux etc. (see below), the available signal is 0.2 V for black, so that the noise in the resistor is no longer of any importance. The remaining difficulty is the Schottky effect, that is the fluctuation in the emission by the photocathode and secondary-emission electrodes, also present in the ordinary type of photo-electric cell, but which could be ignored in that case when compared to the noise originating in the load resistor.

The fluctuation in the electron stream is represented by $1.4p\sqrt{2eI_a\Delta f}$, where e is the charge of the electron, I_a the current supplied by the photocathode and p the internal gain factor of the tube (the factor 1.4 in this expression is applicable to modern types of secondary-emission tubes in which each electron releases an average of 5 secondary electrons). With $p = 50,000$ and I_a (on white) = 14×10^{-4} A, the signal current is 70 μ A and the ratio of noise to signal approximately 0.007, which is quite reasonable (43 db). There is also the advantage that when the luminous flux decreases the noise-to-signal ratio increases only in proportion to $\sqrt{I_a}$ (in the case of noise due to the resistor the proportion is $1/I_a$!). On black, too, the amount of "noise" is very small, being only 1% of the signal. This means that variations in the density of the reproduction due to this noise are hardly perceptible even in the black parts where they are proportionally greatest.

The above-mentioned sensitivity of the secondary-emission cell (1A/lumen) requires a potential of about 150 V per stage and this, in the case of a

⁵) A description of a secondary-emission photo-cell is given in Philips Techn. Rev., 3, 138, 1938. At the time a magnetic field was employed for focusing the electrons onto the successive secondary-emission electrodes, but nowadays electrostatic focusing is preferred, as being the simpler method.

new light-source and freshly cleaned optical system, with new valves in the amplifier and so on, will give a signal of from 2 to 7 V. In actual practice the tube is so adjusted that, with the equipment in the new condition, the signal is reduced to the previously mentioned level, i.e. 10 times lower, by reducing the sensitivity of the secondary-emission cell. This is effected merely by reducing the voltage applied per stage. As soon as the equipment shows signs of ageing the signal can be restored to the original level by raising the voltage on the photo-electric cell. A control knob, with meter for measurement of the signal, is fitted to the exterior of the equipment for this purpose.

An oscillogram of the signal as produced by the transmitter when scanning typescript on white paper is reproduced in *fig. 5*.

The commencement of each line is indicated by an extra high voltage peak (whiter than white) and the end of the line by an extra low value. The first of these impulses is used for synchronisation of the receiver, whilst the combined impulses — as will be explained in the fourth article in this series — ensure that the various tones are all faithfully reproduced at the receiver. This is rendered possible by ensuring that the amplitude of these impulses is constant; in fact this amplitude corresponds to 110% and 0% reflection respectively. These impulses are generated optically by the scanning spot, which, just before striking the conveyor belt and immediately after leaving it, passes

two areas the reflection from which effectively gives these two values. The area that gives "110% reflection" is a frosted aluminium plate. Obviously this plate cannot reflect 110%, but the more or less specular reflection (which does not conform to Lambert's law) results in a luminous flux through

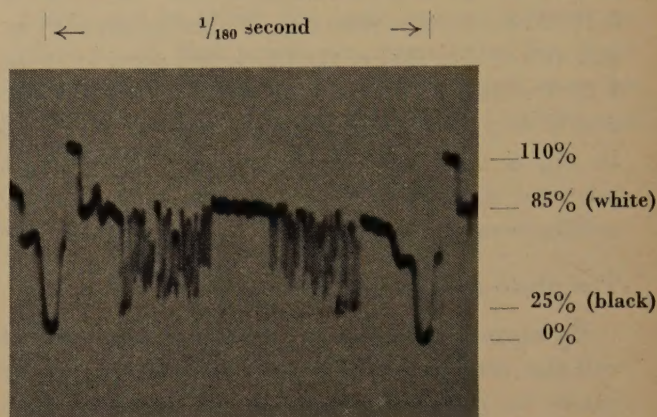


Fig. 5. Oscillogram of signal generated by the transmitter when scanning a typewritten letter: the levels corresponding to black and white are shown at the right. The periodic impulses of extra high and extra low amplitude (equivalent to 110 % and 0 % reflection respectively) provide a density reference scale and permit synchronisation of the receiver with the transmitter.

the part of the objective available for the return beam, which is just as great as that which would be supplied to it by a perfectly diffuse surface capable of reflecting 110% of the light falling upon it.

EXPERIMENTAL TRANSMITTING AND RECEIVING EQUIPMENT FOR HIGH-SPEED FACSIMILE TRANSMISSION

III. DETAILS OF THE RECEIVER

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by F. C. W. SLOOFF *), M. VAN TOL and J. M. UNK *).

In the Philips high-speed facsimile transmission system the signal received, the strength of which varies according to the light and shade of the image being scanned, is employed at the receiver to control the current flowing in a gas-discharge lamp. The varying amount of light from this lamp is projected in the form of a spot onto a film by an optical system rotating in synchronism with the rotor of the transmitter. The film is curved to the cylindrical shape of the rotor and passes the latter continuously, so that the light spot traces on it parallel lines exactly corresponding to the scanning lines at the transmitter. Owing to the very high resolving power of the positive film used, the image can be reproduced in the receiver at 1/6th of the original size, with consequent economy in film. To this end, the diameter of the rotor is only 1/6th the diameter of the rotor at the transmitter, and the recording spot is similarly one-sixth the size of the scanning spot (i.e. 33μ). In this case, too, the rotor carries three identical optical systems and the film is curved only through 120° . Tolerances governing the relative position, size and intensity of the spot in the three optical systems are essentially very small and extreme precision in manufacture of the rotor and in assembly is necessary. Whereas in the case of the scanning spot at the transmitter a circular form is the most suitable, a substantially rectangular shape is better for the recording spot. This is produced by focusing onto the film the image (reduced $4\times$) of a rectangular diaphragm having all four sides adjustable. The lamp, which is capable of following modulating frequencies up to 100 kc/s and the luminous intensity of which is sufficient to produce a density of 1.5 on the film in $5 \mu\text{sec}$, is a gas-discharge lamp filled with mercury vapour and argon at low pressure. The discharge is concentrated within a tube 1 mm in width. A steady current flows through the lamp to assist it in following the necessary high modulation and to give the light-versus-current characteristic the desired form for linear reproduction.

The mechanical features of the Philips high-speed facsimile transmitter have been described in a previous article ¹⁾, and here the mechanical and optical details of the receiver will be reviewed.

General arrangement of the receiver

The type of signal supplied by the transmitter is depicted in fig. 5 of the previous article. In the receiver this signal, suitably amplified, is applied to a lamp specially developed for the purpose and with a luminous intensity capable of keeping in step with every variation of the signal strength. The light from this lamp is used in conjunction with an optical system to provide a recording spot which is synchronised with the scanning spot at the transmitter (i.e. at the same speed and in phase) and traces a succession of straight contiguous lines on a strip of light-sensitive material, thus exposing the latter to a degree determined by the instantaneous values of the signal strength.

The transmitter scans 180 lines per second and each line, 22 cm in length, comprises 1100 image-

elements of the size of the scanning spot (0.2 mm dia.). The receiver, therefore, must be capable of reproducing 180×1100 image-elements per second, each with its own individual density, which means that only $1/200,000$ sec. is available for the exposure of the sensitized film for each elemental area corresponding to a similar image-element in the original.

Although the luminous intensity of the recording lamp cannot be increased to a very high level, since this would interfere with its ability to be modulated up to 100 kc/s, and although the focal aperture of the optical system in the receiver, like that of the transmitter, is limited by requirements relating to depth of focus and image distance, it has nevertheless been found possible to ensure sufficient density within the very short time available by using ordinary positive film as recording material.

This material is certainly more costly than the recording paper used in the slower types of facsimile equipment. The resolving power of the film (55 lines per mm) is, however, very much higher than is necessary for a scanning and recording spot of 0.2 mm. The receiver is therefore designed to work with a light-spot 1/6th of the size and to give a reproduction 1/6th (linear) of the size of the

*) N.V. Philips' Telecommunicatie Industrie (formerly N.S.F.), Hilversum.

¹⁾ D. Kleis, F. C. W. Slooff and J. M. Unk, Details of the transmitter, Philips Techn. Rev. 10, 257-264, 1949 (No. 9).

original document. The consumption of film is thus reduced to $1/36$ th of what it would otherwise be and the cost is therefore of very little importance.

The actual construction of the receiver is similar to that of the transmitter; see *fig. 1*. A 45-mm film continuously passes through the machine and at a given point is curved around a cylinder the radius of which is only $1/6$ th of that of the scanning cylinder

at the transmitter. A rotor mounted coaxially in this cylinder and revolving in synchronism with the transmitter rotor at 3600 r.p.m. carries three identical optical systems, spaced at 120° . Each of the latter contains a diaphragm illuminated by the lamp, which is stationary in the axis of the rotor. An image of this diaphragm, 33 microns in size, is projected onto the film as the recording

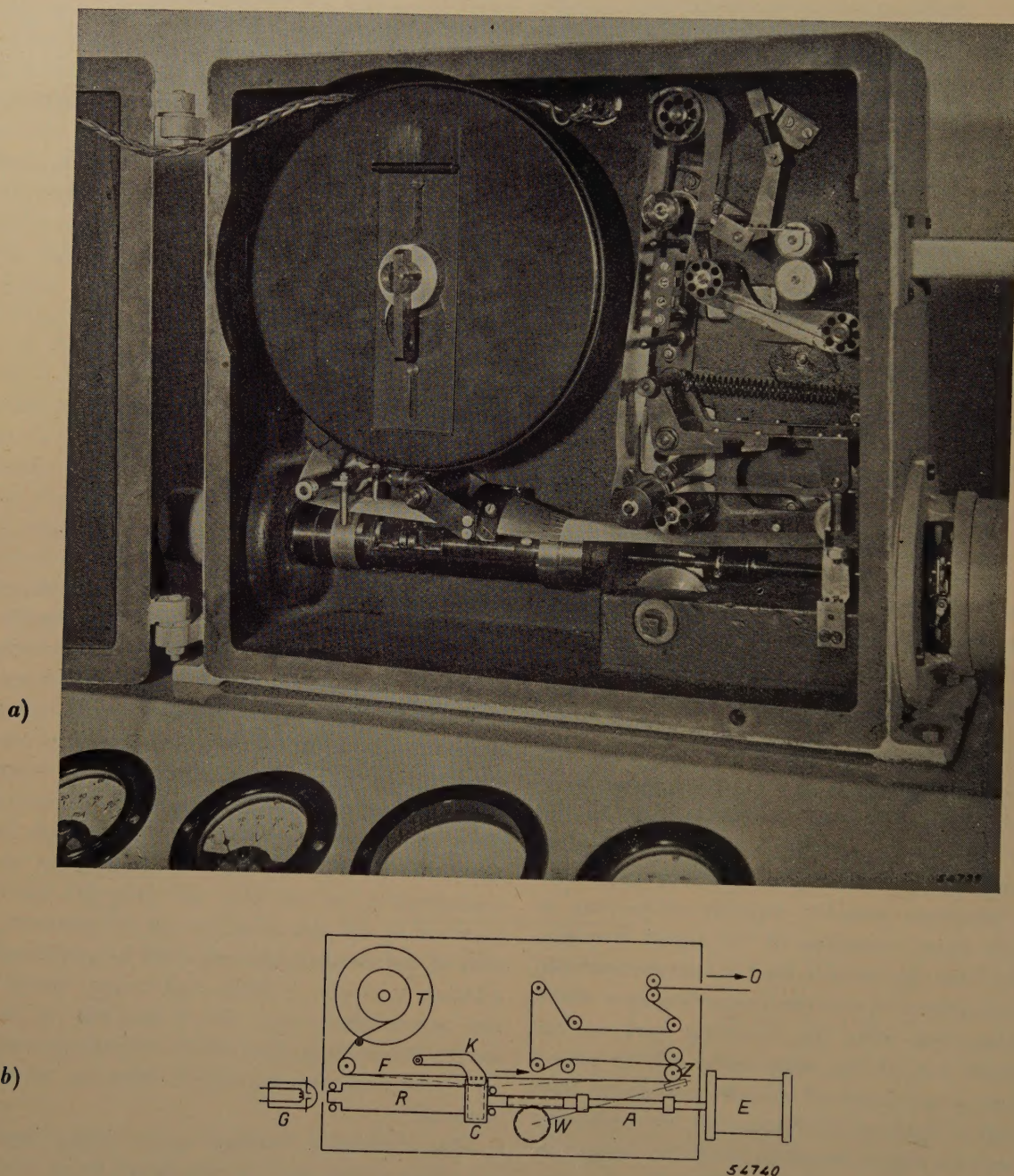


Fig. 1. a) The receiver with cover open. b) Schematic cross-section. The rotor *R* and the stationary recording cylinder *C* are $1/6$ th the diameter of the corresponding parts of the transmitter. The 45 mm film *F* from the spool *T* is curved over the cylinder *C* by a specially shaped spring; at this point a light-spot 33 μ in width produced by the optical system in the rotor and originating in a gas-discharge lamp *G*, which is modulated by the incoming signal, traces parallel lines on the film. The rotor driven by motor *F* by means of a flexible shaft *A* is synchronised with the rotor of the transmitter. Roller *Z* pulls the film passes into a tank where it is automatically developed and fixed.

spot. The movement of the rotor causes each of the light-spots from the three optical systems to trace a line $33\ \mu$ in width across the surface of the film. The rotor and the film-feed mechanism are coupled together by suitable gearing to give a rate of feed of film equal to 1/6th of the speed of the conveyor belt in the transmitter, that is $33\ \mu$ per line or 6 mm per second. The film spool contains about 120 metres of film, sufficient for recording 2400 documents of quarto size, without interrupting the operation, covering a total working period of $5\frac{1}{2}$ hours.

The exposed film is developed and fixed continuously and automatically in a developing tank mounted on the receiver. Subsequently each document recorded on the film can be immediately enlarged to the original size. As each document can be exposed as a whole, exposure times of a few seconds can be applied. Moreover the lamp employed for the purpose may be of high intensity, so that the film can be enlarged on ordinary photostat paper.

In principle, any one of three different methods could be used for the enlarging process, viz:

- 1) to run the film through the enlarger continuously together with a strip of printing paper;
- 2) to project the documents one by one on separate sheets of paper, compensating the continuous movement of the film in the usual manner by means of a moving optical system;
- 3) as 2), but in this case the compensating optical system can be dispensed with by feeding the film through the enlarger intermittently instead of continuously.

If the latter method is to be fully automatic, some form of mechanism is required to ensure that the film moves forward each time at the commencement of each document, even though the original documents may not be fed into the transmitter at regular intervals; this could be effected by various means suited to the particular purpose for which the high-speed facsimile system is to be used. For the transmission of letter post the following system has been evolved. A row of equally spaced black squares is printed at the top of each letter in the manner shown in fig. 2. Scanning of these produces a periodic signal at a frequency of 4 kc/s of about $\frac{1}{3}$ second duration, and this signal energizes a tuned circuit in the receiver, arranged so as to operate with a suitable delay and this in turn operating a punching mechanism via a relay. In this way a hole is punched in the film to register the commencement of each separate communication. (The method of perforation does not affect the movement of the film at the recording point.) When the film is approaching the printing machine the punched holes in it serve to control the click-mechanism on the film drive by means of a "feeler".

A brief survey of some of the other features of the equipment may be of interest.

The recording lamp

The problem of modulating a beam of light at high frequency is encountered not only in facsimile transmission but in many other spheres as well, e.g.



Fig. 2. When the facsimile equipment is to be used for letter post a row of black squares is printed at the top of each letter head. The signal generated by scanning these squares operates a punching mechanism in the receiver which pierces a hole in the film at the proper point. By this means the subsequent movement of the film is made to control a click-mechanism and to register the film correctly for each enlargement separately.

in television, light-beam telephony, etc. This problem has been solved in different ways to suit the various well-known requirements, either by using a constant light-source in conjunction with an optical device of which the transmission factor is varied mechanically or electrically (as in the Kerr cell), or, again, by direct modulation of the power supply of different types of light-source such as in an incandescent lamp, a gas-discharge lamp or a cathode-ray tube. A modulated incandescent lamp or a gas-discharge lamp provide simple solutions, but owing to the thermal inertia of the filament an incandescent lamp is not suitable for modulation frequencies of 100 kc/s. A specially designed gas-discharge lamp, however, has been found capable of fully meeting these modulation requirements.

Before going into details it will be useful to mention one or two other requirements entailed in the design of this part of the equipment. The brightness of the discharge must be high enough to produce on positive film a density ²⁾ equal to 1.5 or

²⁾ This is $\log I_0/I$ when the portion I of the luminous flux I_0 falling upon an exposed film is transmitted.

rather more if possible in the exposure time of 5 μ sec. Further the light beam has to be constant over a sufficiently wide angle in order to fill the rotating optical system with light, without necessitating large distances between lamp and rotor (or a very long rotor; see below). For practical reasons the required currents and voltages must not be too high and, finally, the characteristic (relation between luminous intensity and current or voltage) of the recording lamp must conform to certain other requirements.

Effective modulation of the beam can be expected only from a discharge lamp having a comparatively low gas temperature. In the case of an elevated gas temperature such as usually accompanies high gas pressures and which, it is true, is very advantageous from the point of view of a high luminosity (high-pressure and super-high-pressure mercury vapour lamps), the thermal inertia is usually so great that the emission of light is unable to follow closely any rapid variation in the applied power. One way of obtaining a gas discharge at a low temperature, but nevertheless with a very high brightness is to concentrate the so-called positive luminous column in a very narrow tube (nozzle) and use the light emitted in the longitudinal direction, this being the principle of Ewest's "Lichtspritze"³⁾. In this type of lamp the anode, in the form of a ring, is placed in front of the nozzle mentioned above; the use of an incandescent cathode ensures relatively low ignition and working potentials, with long life. Existing types have proved capable of modulation up to 15 kc/s and of producing the desired density on film in about 100 μ sec.

The lamp developed by Philips is based on similar lines. Modulation is effected by varying the current. A few details of the methods employed to obtain the required higher brightness and better modulation response may be of interest.

Concentration of the luminous column within a nozzle of very small dimensions not only increases the brightness but also the modulation response. This will be appreciated when it is considered that there will be little inertia in the discharge if a surplus of ions can disappear quickly and a shortage of ions can quickly be made good by new ones. For the disappearance of ions a short transit time between the electrodes, that is a short discharge path, is necessary. The recombination of ions, which also assist in eliminating any surplus, can be promoted by reducing the diameter of the nozzle, due to the fact that recombination takes place mainly at the

walls, whilst the ratio of wall-area to volume is inversely proportional to the diameter.

For the highest possible modulation response, therefore, a reduction of the cross-sectional area of the nozzle and of the length of the discharge is the solution. At a certain point, however, these conditions will conflict with the requirement that the brightness must also be high. Light being emitted longitudinally, it is evident that any reduction in the length of the discharge must have an adverse effect on the brightness (selective absorption is of minor importance at the low gas pressures in question). For a given diameter d the nozzle therefore has to be of such a length as to furnish the required width of beam (relation of diameter to length of the nozzle). Similarly, regarding the effect of the diameter the modulation response and brightness are no longer proportional to each other when a certain point is reached, since the current density in the nozzle is limited by the admissible temperature of the wall. For a given wall temperature and angle of emission, a rough calculation will prove the brightness to be $\sim \sqrt{d}$ and the necessary current $\sim \sqrt{d^3}$. As soon as the permissible wall temperature is reached any increase in brightness therefore actually demands a larger diameter of the nozzle. In that case, however, the required power of the source of current, which following on the above increases directly as the third power of the brightness, must also be taken into consideration.

Another important factor in the design of the recording lamp by means of which the modulation response as well as the brightness can be effected is the choice of gas-filling. Both these properties appeared to be very suitable when the lamp was filled with a mixture of argon and nitrogen at a few millimetres mercury-pressure. Theoretical considerations may well explain that a good modulation response is thus obtained: both argon and nitrogen particles are relatively light and thus involve only short transit times. Moreover, it appears to be important that by colliding with nitrogen molecules, metastable, excited argon atoms, which owing to their long life would delay and therefore unfavourably influence the modulation response, can lose energy. From the aspect of spectral distribution of the light emission, too, an argon-nitrogen mixture is favourable, as the emission is preponderantly blue and violet, these being the colours to which positive film is most sensitive. However, a well-known disadvantage of this gas mixture of a gas discharge in which the current density is high is that in the course of time the nitrogen disappears

³⁾ H. Ewest, Z. Techn. Phys. 12, 645, 1931.

from the mixture, presumably through its combining with the cathode metal to form a nitride.

Excellent results, without disadvantages, are obtained with a mercury-vapour discharge at very low pressure, containing argon to keep the ignition voltage down to a low value. Theoretically the modulation response will not be so good as in the case of the gas-filling previously mentioned, since the heavy mercury atoms require much longer transit times. This has been confirmed in practice, but it has nevertheless been found possible to obtain the desired modulation up to 100 kc/s with adequate brightness ⁴) (argon-nitrogen mixtures actually made it possible to record modulation frequencies up to 300 kc/s). This result is partly due to the dimensioning of the nozzle, which approximates the optimum compromise, viz. 1 mm wide and 5 mm long with anode and cathode as close as possible to the ends of the nozzle. Good modulation response is partly due to the fact that a certain steady current is allowed to flow through the lamp even in the absence of signals, thus ensuring a reserve of ions which enables the formation of the required fresh ions to take place much more rapidly when the signal increases from zero than if the discharge were completely extinguished.

The relation between the luminous intensity and the lamp current is by no means linear, as might be considered desirable at first sight. In practice, however, this is not a disadvantage, but even an advantage, since it partly assists in compensating for the very pronounced non-linearity in the density curve of the positive film in question. In connection with this, the actual value of the steady current of the lamp is of special importance. The density of the enlarged print made from the film negative can in this way be made to approximate very closely the density of the original document, which is the essential requirement for a true reproduction of half-tones. If the facsimile apparatus were to be used only for the transmission of black-and-white images the characteristics of the lamp used would not be very important; the only requirement would be a sufficiently high intensity to expose the film to the necessary degree for the black part of the image.

A further advantage of the mercury-vapour filling is that the maximum luminous flux required is attained for a current of only 70 mA (at a working voltage of 30 V), so that it is possible to feed the

lamp from a single output valve of the EL 6 type (argon-nitrogen necessitates three of these valves in parallel).

The design of the lamp used is shown in fig. 3a, whilst a photograph of the lamp is given in fig. 3b.

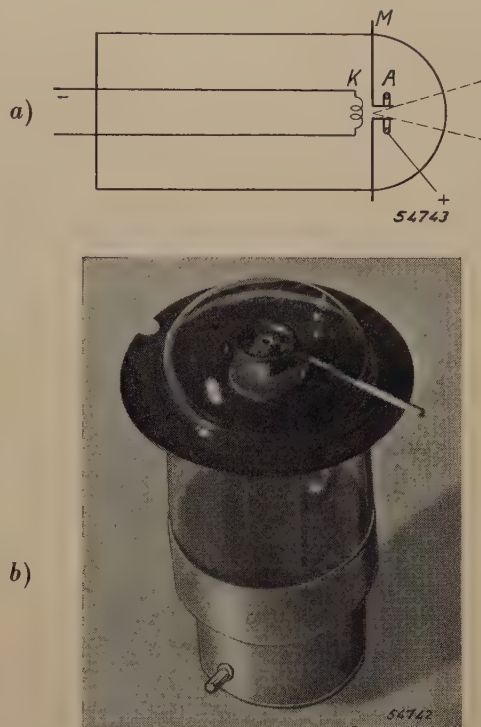


Fig. 3. a) Schematic cross-section, b) photograph of the lamp. A concentrated discharge of relatively high brightness occurs in the narrow tube nozzle between the cathode and the annular anode *A*. Due to the carefully proportioned system of electrodes, the luminous flux is capable of responding accurately to current modulations up to 100 kc/s. The tube is mounted on a molybdenum disc *M*, which also serves for alignment purposes.

To prevent the discharge from taking any path other than through the nozzle the latter is fixed to a molybdenum disc sealed into the glass bulb and dividing the lamp into two separate compartments for the anode and cathode, the connection between these compartments being formed by the nozzle. At the same time this molybdenum disc, which projects outside the wall of the bulb and which can be manufactured with a high degree of precision, facilitates centring of the light-spot exactly in the axis of the rotor in the receiver.

The optical system of the receiver

Fig. 4 is a cross-sectional diagram of the rotor, showing details of the optical system. A set of three mirrors (S_1) arranged around the axis of the rotor transmit radially three beams of light from the stationary lamp at angles of 120° . Each beam is then deflected in a direction parallel to the axis by

⁴) The spectral distribution of the light of the mercury discharge is in fact even more favourable than that of argon-nitrogen.

another mirror (S_2) and is concentrated by a condenser onto a diaphragm. A microscope objective of numerical aperture 0.3 then throws a 4 times reduced image of the diaphragm via a final mirror (S_3) onto the film.

The numerical aperture of the objective, which together with the brightness of the lamp determines the luminous flux of the light-spot, was not made larger for the reason already given in connection with the transmitter, i.e. the distances must not be too small as otherwise the depth of focus will be insufficient. To manage with the same depth of focus as in the transmitter, the absolute tolerances in eccentricity of the rotor or cylinder, vibration etc. are only 1/6th of those which are admissible in the transmitter, in view of the corres-

in the rotor is restricted to the necessary degree by carefully machined thrust bearings at each extremity, whilst, moreover, the rotor is protected from vibration as much as possible by coupling it to the motor by means of a flexible shaft. Uniformity in the movement of the film is maintained by keeping it taut between the recording cylinder and the driving roller. An advantage in using film is that it can be easily curved to make close contact with the cylinder; this is effected by means of a curved spring.

At this point the reason for a reduction factor of only 4 being chosen for the projection of the diaphragm onto the film will become clear. A larger factor would have been more convenient from the point of view of handling the diaphragm (now only 0.13 mm in width), but this would have necessitated

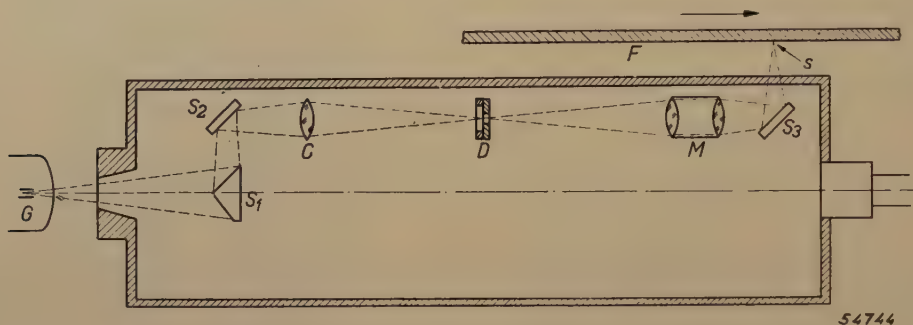


Fig. 4. Diagram of one of the three optical systems in the rotor. G stationary recording lamp; S_1 , S_2 mirrors; C condenser; D diaphragm; M microscope objective; S_3 mirror, s recording light-spot on the film F .

ponding reduction in size. In fact these tolerances have to be even closer, since fluctuations in the size of the spot in the receiver are more troublesome than in the transmitter; variations of as little as 20% will give the image a badly striped appearance. The relative dimensions of the three light-spots therefore must not differ more than about 6 microns, and similarly tangential or axial discrepancies in the location of the spot must not exceed 6 μ . Irregularities in the motion of the film and axial movement of the rotor are subject to the same tolerance. The luminous flux of the three light-spots individually must not differ more than 10%.

To satisfy such requirements it was necessary to maintain a degree of precision in the manufacture of the rotor approaching the limits of practical achievement ⁵⁾. All the lenses and mirrors as well as the diaphragms are adjustable, so that the proper location, size and brightness of each of the light-spots can be adjusted individually. Axial movement

a longer light path and therefore a longer rotor, which in turn would have increased the problem of the bearings and the suppression of vibrations.

From the known reduction in the size of the image in the diaphragm it is a simple matter to determine the aperture of the beam of light from the lamp, to which reference has frequently been made in the text. In order to fill the objective with light, the angle β in fig. 5 must be made at least equal to angle α as determined by the reduction factor and the numerical aperture of the objective. It is advisable to have an image

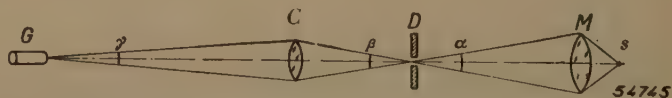


Fig. 5. The light-path in one of the three optical systems, from the light source G to the recording light-spot s , determining the conditions governing the aperture γ of the light beam. C condenser; D diaphragm; M objective.

of the light-source as formed in the diaphragm by the condenser, with a diameter of approximately 0.5 mm in order to allow sufficient latitude in the location of the diaphragm. The diameter of the nozzle of the recording lamp is 1 mm, so the image of it produced by the condenser must be reduced 2 times, from which it follows that $\gamma \approx \frac{1}{2} \beta$, that is $\gamma > \frac{1}{2} \alpha$. A larger aperture is advantageous, other things being equal,

⁵⁾ Acknowledgements are due to Mr. H. Grandjean Perrenod-Comtesse of N.V. Philips' Telecommunicatie Industrie, who played a very active part in the mechanical construction of the rotor and other parts of the receiver; notably the above-mentioned punching device.

and the distance between light-source and condenser and between the latter and the diaphragm (which also determines to some extent the length of the rotor) can then be made smaller.

The shape of the recording spot at the receiver and of the scanning spot at the transmitter

To avoid a striped appearance of the image the lines traced by the three light-spots must not only be actually contiguous but each line, measured across its width, must be of equal density. The

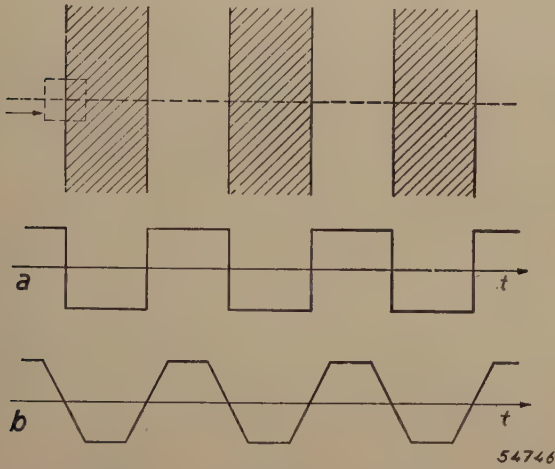


Fig. 6. a) Idealised signal supplied by the transmitter when scanning a black and white grid. b) Pattern produced on the film by modulation of the luminous intensity of the receiving lamp, in accordance with (a). Owing to the finite width of the recording spot the boundaries between the black and white lines of the grid as reproduced are not sharply defined.

light-spot, therefore, must not be round but rectangular. Of course the most obvious shape would then be square, but this does not actually give the best results. Suppose that the transmitter is scanning a grid of black and white lines, which in the idealised case would give a signal consisting of pure square waves, see fig. 6a. The recording spot will vary in brightness in an exactly similar manner, but owing to the finite length of the spot in its travelling direction the transition between black and white will be blurred (fig. 6b). In order to limit this effect the longitudinal dimension in question is made slightly smaller than the width, viz. in the ratio of about 2 : 3. The spot cannot be made much shorter as this would reduce the exposure time at each point on the film below the required level.

If the exposed lines on the film, the centre distances of which are 33μ , are to be really contiguous, the image of the diaphragm must be slightly less than 33μ in width; scattering of the light in the film then ensures an effective width of spot of exactly 33μ .

It must of course be possible to adjust the three diaphragms in the prescribed form and, further, to

render each one displaceable as a whole. Each of the diaphragms therefore comprises the aperture between four blades, all lying in the same plane and each one capable of a small amount of adjustment in this plane.

In this connection it should be realised that the requirements imposed by the scanning spot in the transmitter are very different from those to which the recording spot in the receiver must conform. The function of the former is merely to make possible the measurement of the local "blackness" of the document or, in fact, its average value within an area equal to the smallest detail to be transmitted, i.e. a square of $0.2 \text{ mm} \times 0.2 \text{ mm}$. Since we are prepared to accept the fact that no detail will be distinguishable within an area of that size, it is also permissible in principle to assume that the density is uniform within that area. It therefore makes very little difference if the scanning spot covers slightly less than the whole area. In the transmitter it is thus quite permissible to employ a circular spot, which involves much less difficulty in manufacture than the rectangular form. Curiously enough it can be shown that, as far as the scanning spot is concerned, a circular form is actually better for the purpose than a square (or rectangular) form. Let us once more assume the transmission of a black and white grid, in which the width of the lines is equal to the resolving power of the scanning spot (i.e. its "longitudinal" dimension). The resultant signal will not be of rectangular wave-form as argued above, but in the case of a rectangular spot will be triangular or "saw-toothed", see fig. 7a, for when the light-spot

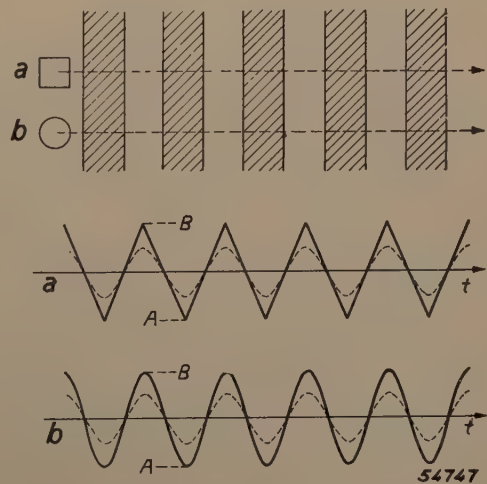


Fig. 7. a) Signal produced by the transmitter when scanning a grid as shown, using a rectangular scanning spot (length of spot equal to the width of the grid lines). b) The same as applied to a circular scanning spot (diameter equal to the width of the grid lines).

moves from a black line to a white one the increase in that part of it which is filled with "white" is linear with time, hence the increase in signal strength is linear from the lowest value (A in the black) to the highest (B in the white). The boundaries between the black and white lines will therefore be reproduced with a lack of definition even if there were no blurring effect caused by the recording spot at the receiver. In the case of a circular spot, however, the luminous flux intercepted in the scanning of the grid follows the sinusoidal (dotted line) curve shown in fig. 7. It is true that the slope at the steepest parts of the gradient, which determines the extent of the blurring, is then exactly the same as in the case of the saw-tooth characteristic, but as the levels of black and white (A and B respectively) must be the same in both

cases, after amplification the curve takes the form shown in fig. 7b, from which it will be seen that the slope is now much steeper than that of the saw-tooth curve. The round scanning spot, therefore, ensures better definition.

These considerations apply only where the satisfactory reproduction of half-tones is concerned; for purely black and white images a different method of amplification is employed and the circular scanning spot no longer has any advantage over the rectangular. In this case the signal is actually cut off sharply at top and bottom after suitable amplification and the arbitrary cut-off levels are employed as "black" and "white" respectively. This, however, brings us into the province of the electrical circuits, which are to be reviewed in the following article.

GLASS TRANSMITTING VALVES OF HIGH EFFICIENCY IN THE 100 Mc/s RANGE

by E. G. DORGELO.

621.385.13:621.316.615

A new series of glass transmitting valves introduces a reversion from the flat type of electrode to the older arrangement of concentric cylindrical electrodes. A number of reasons are given for the change, based on electrical, mechanical and thermal considerations. Apart from the cylindrical arrangement of the electrodes, the more outstanding features of the new valves are a spiral cathode of thoriated tungsten, a non-emissive grid, a graphite anode with horizontal cooling fins in the form of a cotton-reel, and a shield to reduce the temperature of the bottom edge of the envelope and the base (thus keeping the electrical insulation high), the whole being assembled in an "all-glass" envelope, without the usual moulded base. In the triodes this shield is connected to the grid, enabling the valves to be employed in grounded-grid circuits without neutrodyne even at 200 Mc/s. In the tetrodes this shield is attached to the screen-grid, and neutroding is necessary only at frequencies above 100 Mc/s (approx). Various details are given of the triode TB 2.5/300 and the tetrode QB 2.5/250 (anode dissipations 135 and 125 W respectively). At 100 Mc/s the efficiency is still 70 to 65%. Similar valve types for higher power are in course of development.

Comparison between the cylindrical and flat types of electrode system

The very oldest types of transmitting and receiving valves were usually made with a straight filament as cathode, with coaxial, cylindrical ¹⁾ grid and anode.

At a later stage the single filament was extended to a number of wires, all suspended in the same plane and surrounded by a flat grid and also a flat anode. The reason for this development was a desire to obtain a characteristic (anode current as a function of the grid voltage) with the highest possible slope. This arrangement necessitated a longer cathode, and by designing a filament in the form of a flat zig-zag with one face of the grid on each side of it a form of construction resulted which ensured mechanical rigidity as well as an enhanced effect of the grid potential on the anode current.

In recent years, however, there has been a growing tendency to revert to the original cylindrical construction, though in a modernised form. The fact that this does not adversely affect the slope of the characteristic is mainly due to the improved assembly methods, which have led to a considerable reduction in the space between grid and cathode.

We shall now briefly analyse the reasons for this change in policy, under the headings of electrical, mechanical and thermal considerations.

Electrical advantages of the cylindrical electrode system

a) Let us first compare the potential distribution, in the direction from grid to anode, in a valve having cylindrical, coaxial electrodes with that in

one having flat electrodes, for the same potential difference and equal spacing of the electrodes. In the cylindrical system the potential increases more rapidly than in the flat system; it follows that the electron transit time in the former must be shorter than in the latter, for the electrons more rapidly acquire velocities approaching the final velocity (which is determined solely by the potential difference between anode and cathode). This immediately gives the cylindrical arrangement the advantage, since the transit time, when it becomes comparable with the oscillation time, reduces the efficiency.

b) In the cylindrical construction the current density is highest at points close to the cathode and decreases as the distance from the cathode becomes greater. Owing to this an undesired effect, namely a decrease in the space-potential, is not so pronounced, as will be seen from the following.

In high-frequency transmitting valves the lowest possible capacitance between grid and cathode is essential. Moreover, as already stated, the electron transit time in this part of the discharge space must be short. This implies that there must be small cathode and grid areas and also short distances between these electrodes, resulting as a matter of necessity in high values of the current density within the space in question. When flat electrodes are employed the electron paths are parallel and the current density in the grid-anode space is also high; in this region it tends to produce a local decrease in the space-potential (when the latter drops to zero we speak of a "virtual cathode") which causes part of the electrons to be thrown back. The grid current then rises at the cost of the anode current. The effect in question is less evident

¹⁾ In the following the term cylindrical is to be understood in the limited meaning of rotation-symmetrical.

in a valve having cylindrical electrodes, where the electron paths diverge and the current density in the grid-anode space is accordingly lower than between cathode and grid.

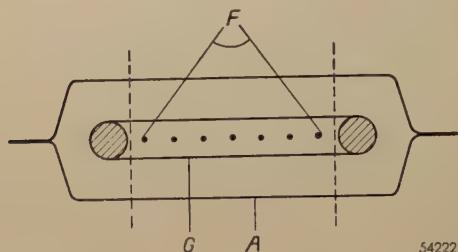


Fig. 1. Cross section of a triode with flat electrode system. F = filament, G = grid, A = anode. Only that part of the electrodes between the dotted lines is effective; parts outside that area add to the stray capacitances.

c) In the flat system of electrodes, a plan view of which is depicted in *fig. 1*, the effective part of the system lies within the area between the dotted lines; the parts outside those limits have an adverse effect, owing to their relatively large contribution towards the inter-electrode capacitances and also to the longer transit time of electrons which have penetrated to those outlying zones. With the cylindrical construction there are no such zones.

Mechanical advantages

A second group of advantages of the cylindrical arrangement is mainly to be found in the mechanical features.

d) In directly-heated transmitting valves the cathode often consists of a tungsten filament to which a small percentage of thorium oxide has been added ²⁾. To ensure a high specific emission the filament is heated during the manufacturing process in a gas containing carbon, thus producing a superficial layer of tungsten carbides ³⁾.

It is a well-known fact that such carburized filaments are not strong mechanically, owing to the brittleness of the carbide layer, in which cracks very easily occur and lead, in turn, to internal fracture. Risks of filament breakage can be considerably reduced by employing a spirallised filament, since a spiral can easily withstand small variations in length as well as lateral displacement.

Although in principle it would be quite possible to arrange a number of spirals in a row, i.e. in one

plane, the more obvious solution is to employ a cylindrical configuration. In that case it is usual to assemble two (or more) spirals on the same cylindrical plane (see *fig. 2*), with the top ends of the spiral attached to a robust axial support, this arrangement being very resistant to shocks.

The springs usually employed to keep the straight filament taut are then not necessary, and this eliminates also the extra capacitance normally introduced by such springs, as well as the often complicated discs of insulating material required to hold the springs in position and insulate them from each other. The absence of these spacers in turn removes a source of dielectric losses.

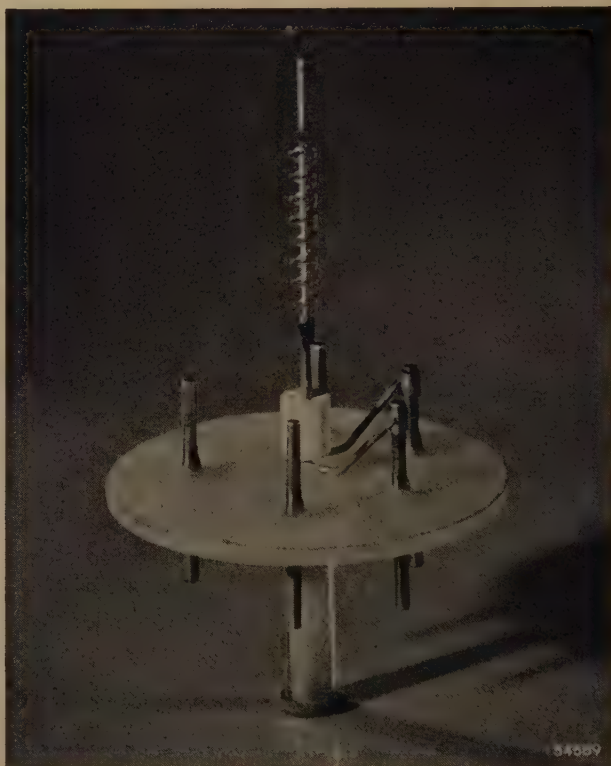


Fig. 2. Cathode consisting of two coaxial spirals of thoriated tungsten.

e) The manufacture of anodes of cylindrical form is very simple. If the material is to be graphite, as in the case of the valves under discussion, the whole anode, including any desired cooling fins, can be turned from a solid piece. When the anode becomes hot the circular form is maintained. Small discrepancies in the diameter or a slight eccentricity have little effect on the inter-electrode capacitances or electrical characteristics.

f) The fact that the electrodes all take the form of concentric cylinders simplifies assembly and facilitates accurate centring of the electrodes mutually. Rotary mounting and sealing machines permit

²⁾ See S. Dushman, *Electron Emission*, Trans. Am. Inst. El. engrs. **53**, 1054-1062, 1934.

³⁾ C. W. Horsting, *Carbide structures in carburized thoriated-tungsten filaments*, J. Appl. Phys. **18**, 95-102, 1947 (No. 1).

highly concentrated mechanisation in the manufacturing processes (*fig. 3*).

Thermal advantages

Finally, the cylindrical electrode system offers a number of advantages from a thermal aspect (though these might in part equally come under the heading of mechanical advantages).

Further, the cylindrical arrangement is well adapted to the "cage" type of grid (*fig. 4*), which consists of a rather large number of rods mounted like describing lines of the surface of a cylinder, with hardly any winding wire. These grids are very robust and self-supporting and they are highly conductive to heat as well as to high-frequency currents. This type of grid is employed in the

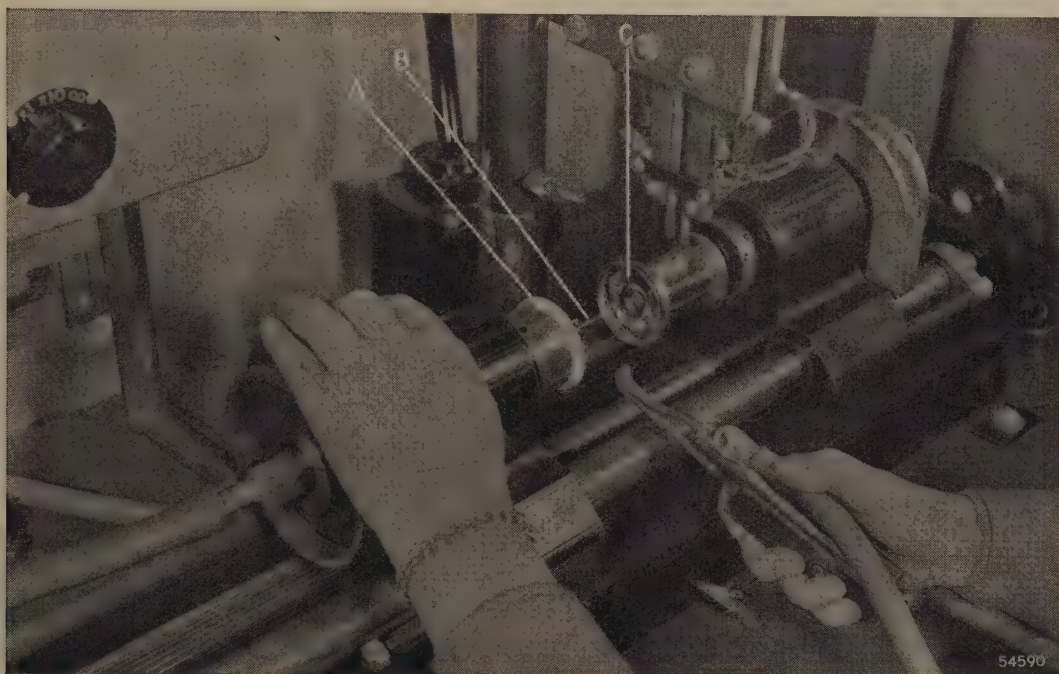


Fig. 3. Machine used for mounting cylindrical electrode systems. *A* = powder-glass base with leading-in pins and filament *B* (cf. *fig. 2*), *C* = shield to which the grid is connected. By rotating the machine head against which the glass base *A* is held by a vacuum, the operator accurately centres the filament in the grid, then welds the latter in position by means of the special welding pliers seen in the photograph. Extreme left: control knob for timing the weld.

g) The spirals of which the cathode consist are free to expand, even though the extremities are anchored; moreover, in a given valve type the expansion is uniform between one specimen and another.

The latter also applies to the grid and anode. At given temperatures of the electrodes, measurement of the internal capacitances yields almost the same results in every case.

h) With the flat grid one of the greatest sources of trouble is the irregular expansion of the turns of wire; the greatest expansion occurs at the centre, where it is hottest, and the turns at that point tend to go awry. If they buckle inwards they are likely to touch the filament. In the case of helical grids there is much less distortion and in any case this takes place outwards, so that there is no risk of shorting to the filament.

valves described in the following paragraphs (except in the smallest models).

i) The electron stream to an anode of cylindrical form is uniformly distributed over the whole periphery. The same applies to the temperature, not only at points along the length of the anode but also along the wall of the bulb, a fact that favours good operating conditions.

The radiation of heat from the anode can be facilitated by providing cooling fins, either vertical or horizontal, the latter being preferable, as the anode can then be manufactured by machining on a lathe (*fig. 5*). The size of the cooling fins depends to a large extent on the distribution of the temperature over the cross section through the axis of the bulb. This point is referred to more fully in a following section.

The shape of the anode with horizontal "fins" is



Fig. 4. Cage type of grid with shield at the base to screen the cathode electrically and part of the glass envelope thermally.

somewhat reminiscent of the domestic cotton reel; hence these valves are sometimes referred to as "cotton-reel valves".

A new range of transmitting valves of cylindrical construction

The various factors outlined above have led to the design of a new range of transmitting valves, two of which, the triode TB 2.5/300 and the tetrode QB 2.5/250, are already in production, others being still in course of development.

Before discussing the electrical characteristics of these valves, let us first look at some features of the electrodes and envelope.

The electrodes

The cathodes in the new valves are of spirallised thoriated tungsten, of the type mentioned above, these being carburized to increase the emissivity.

Until now, two difficulties have stood in the way of a universal application of this type of cathode. Firstly, thorium evaporated from the cathode and deposited on the grid very quickly produces electronic emission from the latter, whilst, secondly, the only known metal that will ensure a sufficiently low emission of gas (the emission of a thoriated cathode is destroyed by the merest traces of oxygen),

and which is suitable for use for the grid and anode, is tantalum, which is costly.

The first of these obstacles has been overcome in the new range of valves by coating the grid with a substance that absorbs thorium, which, when once diffused within the basic material, is harmless. Moreover, owing to the effective thermal radiation of the anodes with their cooling fins, the temperature of the grids in these valves does not rise considerably and there is therefore little risk of grid emission.

As regards the second point, the discovery of the gas-absorbing properties of zirconium⁴⁾ has made it possible to employ the thoriated tungsten cathode on a much larger scale, in conjunction with an anode of less costly material, such as molybdenum, nickel, or graphite.

The latter lends itself well to the manufacture of anodes with cooling fins from one solid piece (fig. 5), as already pointed out above. The amount of gas given off by the anode — and by the other electrodes as well — after the bulb has been exhausted is very small indeed when zirconium is applied to the anode in the form of a thin layer,



Fig. 5. Circular anode of graphite, with cooling fins, shaped more or less like a cotton-reel. The four molybdenum rods on which the anode is mounted are poor conductors of heat but provide good electrical conductivity.

⁴⁾ J. H. de Boer and J. D. Fast, *Rec. Trav. Chim. Pays-bas* 55, 459-467, 1936; J. D. Fast, *Metals as getters*, *Philips Techn. Rev.* 5, 217-221, 1940.

this being the method employed in the production of the valves under discussion. The high thermal capacity of these anodes constitutes a safeguard against momentary heavy overloads. In fact the anodes are able to withstand overloads of some duration, as witness the fact that one of these valves, intended for a dissipation of 135 W, with a final temperature of 800 °C, was overloaded to the extent of 900 W for half an hour without detriment to the valve.

Four rather thin molybdenum rods are used to support the anode, this arrangement being better than a single thick rod, which, for the same resistance at high frequencies, would have to have a diameter equal to four times the thickness of the thinner rods, since, due to skin-effect, the electrical conductivity is proportional to the periphery and not to the cross section. At the same time the thermal conductivity of one such thick rod would be four times as high as that of four thinner ones together, and the anode lead-in might become too hot. Owing to the distribution (and adequate length) of the rods, the anode lead-in remains comparatively cool.

At a rising frequency and a constant input potential the losses within the valve will increase. Forced air-cooling (by means of a small fan which can simultaneously cool other parts of the transmitter) becomes necessary only at frequencies above 100 Mc/s, at maximum input voltage.

Envelope, leading-in pins and contact pins

The new valves are of the so-called "all-glass" construction. The envelope, at the top of which the anode connection is located, is closed at the bottom end by a flat, pressed powder-glass base⁵⁾ containing five molybdenum leading-in pins, these being sealed into the base in one operation (fig. 6).

Of these five pins two are for the filament. In triodes the other three are attached to the grid, whilst in tetrodes only one serves this purpose, the remaining two being attached to the screen-grid. The intention is that when the valves are used on very high frequencies three grid pins or, similarly, the two screen-grid pins be connected in parallel in order to reduce the self-inductance and resistance (and therefore also the losses which result from the mainly capacitive grid current).

The conventional valve base has been dispensed with, and the leading-in pins, which are of molybdenum, serve at the same time as contact pins. This arrangement has been made possible only by the

introduction of a sealing process which leaves the molybdenum in a ductile condition, thus avoiding breakage of the pins in use.



Fig. 6. Mechanical sealing of leading-in pins into the powder-glass base. Heating is brought about by h.f. induction in graphite jigs.

As these leading-in pins are thinner than the customary contacts in this class of valve, sleeves are soldered to them to give them the desired diameter. The arrangement of the pins (fig. 7), too, is such that the valves can be used in current types of valve-holders.

Considerable attention has been given to the distribution of temperature over the bulb surface, and the cooling fins on the anode have been carefully proportioned to ensure that a large portion of

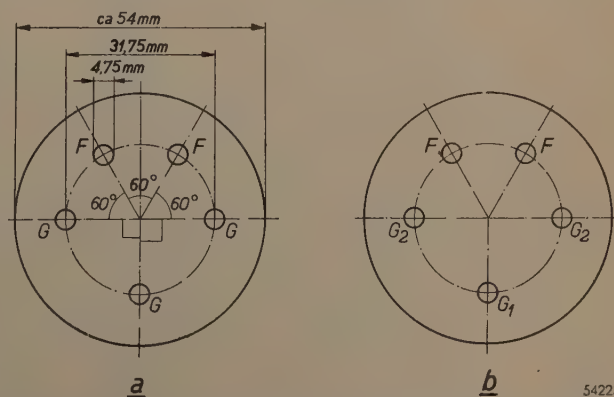


Fig. 7. Arrangement of contact pins in a) triode TB 2.5/300, b) tetrode QB 2.5/250. F = filament; G = grid (with shield), G₁ = control grid, G₂ = screen grid (with shield).

⁵⁾ E. G. Dorgelo, Sintered glass, Philips Techn. Rev. 8, 2-7, 1946.

the heat developed is radiated in an axial direction. This produces an extra supply of heat to the glass around the top seal containing the anode pin, so that there will be only a slight difference between

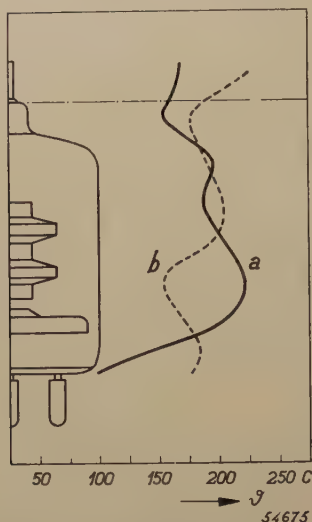


Fig. 8. Temperature θ of the anode lead-in (above the dot-dash line) and along the wall of the bulb (below the dot-dash line). The curve drawn as a full line (*a*) refers to the TB 2.5/300, a half-section of which is shown on the left. The dotted line (*b*) was plotted from a valve of similar rating without cooling fins and fitted with the conventional base. In both instances a static load of 125 W was applied. In the TB 2.5/300 there is very little difference between the temperatures of the anode lead-in and the surrounding glass; a cold zone occurs at the base of the valve, ensuring high insulation resistance.

the temperatures of the lead-in itself and the surrounding glass (see fig. 8, curve *a*). Thermal capacities are such that this applies not only under normal working conditions but also whilst the valve is warming up or cooling off.

Much wider differences in temperature occur in a similar valve not provided with cooling fins (fig. 8, curve *b*).

In a previous article in this journal ⁶⁾ we have mentioned the electrical conductivity of glass, which under certain conditions tends to reach critical levels at high temperatures; in view of this, special kinds of glass have been developed the conductivity of which is low. The valves now under discussion do not, however, call for the use of any special kinds of glass, since sufficient insulation is guaranteed by the long vitreous path between the anode pin and the connections to the other electrodes, which path moreover includes a "cold" zone (fig. 8, curve *a*). This cold zone is ensured by the presence of a metal shield in the valve (figs 4 and 9) which protects the bottom of the envelope, as well as the base, from the effects of thermal radiation.

This shield also fulfils an electrical function, to which reference will be made presently.

The cold zone would not exist if the valve were fitted with the usual type of base, which tends to prevent the dissipation of heat through the bulb. This is illustrated in fig. 8, curve *b*, which shows the distribution of temperature along the envelope of a valve with base. The temperature in the region of the bottom contacts is in this case so high that it is essential to blow air through the base, necessitating a fairly complicated valve holder.

⁶⁾ E. G. Dorgelo, Several technical problems in the development of a new series of transmitter valves, Philips Techn. Rev. 6, 253-258, 1941.

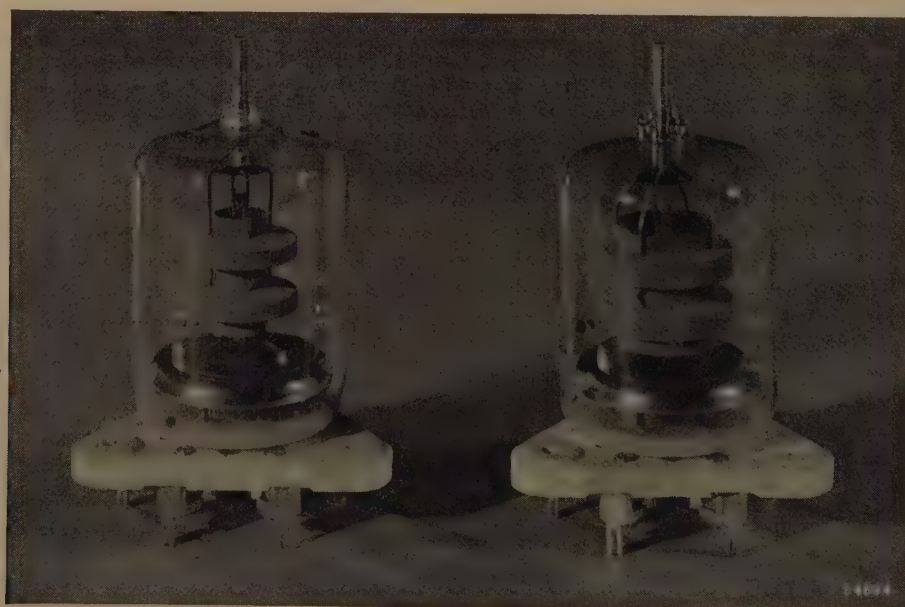


Fig. 9. On the left the triode TB 2.5/300 (anode dissipation 135W), on the right the tetrode QB 2.5/250 (anode dissipation 125W). Height of valves (including the pins) about 123 mm (5").

Electrical data relating to the TB 2.5/300 and QB 2.5/250

The triode TB 2.5/300 is designed for an anode dissipation of 135 W and the QB 2.5/250 for 125 W. The construction of both types is based on the various factors outlined above and the characteristics are shown in *figs 10 and 11*; the filament in each case takes 5.4 A at 6.3 V.

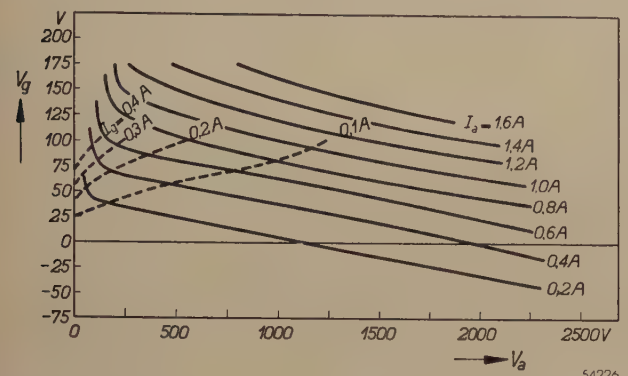


Fig. 10. Characteristics of the triode TB 2.5/300. In place of the characteristics anode current I_a as a function of the grid voltage V_{g1} at constant V_a , or $I_a = f(V_a)$ at constant V_{g1} , the increasingly popular characteristics $V_{g1} = f(V_a)$ at constant I_a are shown (full lines). The broken lines refer to $V_{g1} = f(V_a)$ for a constant grid current I_{g1} .

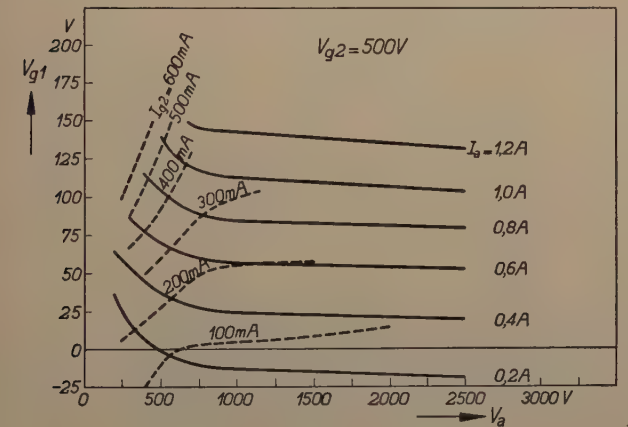


Fig. 11. Characteristics of the tetrode QB 2.5/250 for a screen grid voltage $V_{g2} = 500$ V. Full lines: control grid voltage $V_{g1} = f(V_a)$ at constant I_a ; broken lines $V_{g1} = f(V_a)$ at constant I_{g1} .

In the triode the shield mentioned above is connected to the grid, thereby greatly reducing the capacitance C_{ak} between anode and cathode. The valve is thus rendered very suitable for use in grounded-grid circuits. Usually these circuits employ two valves in push-pull (*fig. 12*), in which case the input circuit is between the cathode and the output between the anodes. Neutrodyne capacitors are then unnecessary, even at the highest frequency at which the valve still works efficiently (200 Mc/s); the amount of coupling between input and output circuits due to the capacitance C_{ak} is in any case very small and is, moreover, almost

wholly compensated in this frequency range by the self-inductance of the three connections to the grid and the shield, which are connected in parallel.

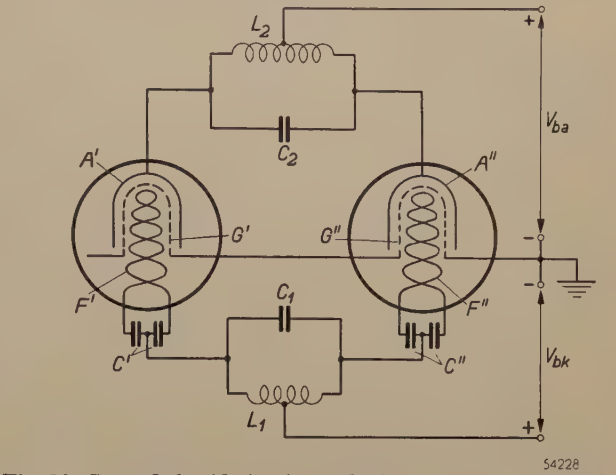


Fig. 12. Grounded-grid circuit employing two triodes in push-pull. G', G'' = earthed grids (and shields). L_1-C_1 = input circuit connected to the filaments F', F'' . A', A'' = anodes to which the output circuit L_2-C_2 is connected. C', C'' = capacitors for h.f. decoupling of the filaments. V_{ba}, V_{bk} = D.C. voltages applied between anode and grid and between cathode and grid respectively.

In the tetrode the shield is attached to the screen grid, resulting in a low capacitance C_{ag1} between anode and control grid. Neutrodynisation is unnecessary on frequencies below about 100 Mc/s. It is not the place to enter here into methods of avoiding coupling between circuits at higher frequencies; suffice it to say that this can be done very simply by interconnecting the screen grids of the two valves in push-pull via a variable capacitor.

Both valve types are intended to serve a large number of different purposes, such as for broadcasting and communication transmitters, oscillators for industrial or medical application (h.f. heating, diathermy, etc.). The efficiency is as high as 65-70% (*fig. 13*) at a frequency of 100 Mc/s, this rendering

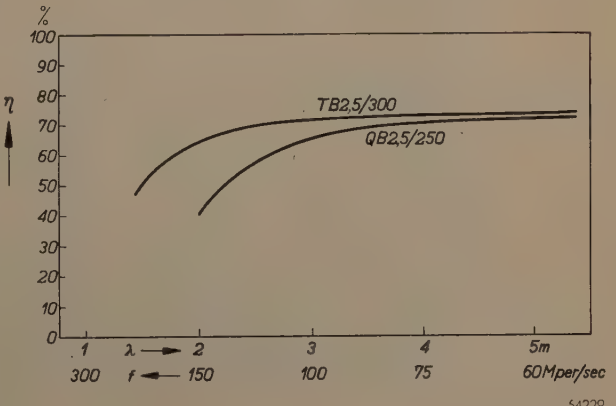


Fig. 13. Efficiency η (as defined in table III), as a function of the wavelength λ (or frequency f), of the TB 2.5/300 and QB 2.5/250. At 100 Mc/s the efficiency η is still as high as 72% and 65% respectively.

Table I. Several class C telegraphy ratings for the triode TB 2.5/300 used as amplifier and oscillator. Voltages are with respect to earth. Where two valves are used the values of current and power are per valve.

Application	Freq. (Mc/s)	V_{ba} (V)	V_{bg1} (V)	V_{bk} (V)	V_{g1max} (V)	I_a (mA)	I_{g1} (mA)	P_{g1} (W)	P_{ba} (W)	P_a (W)	P_o (W)	η (%)
As amplifier:												
Cathode grounded	60	2500	—200	0	350	200	40	14	500	135	365	73
Cathode grounded	60	1500	—120	0	270	200	40	11	300	100	200	67
Grounded grid (fig. 12) .	100	2000	0	150	—	200	40	50	400	130	280	70
As oscillator	150	1700	—130	0	—	200	40	—	340	135	205	60

Table II. As Table I for the tetrode QB 2.5/250, used as amplifier.

Circuit	Freq. (Mc/s)	V_{ba} (V)	V_{bg1} (V)	V_{bg2} (V)	V_{g1max} (V)	I_a (mA)	I_{g1} (mA)	I_{g2} (mA)	P_{g1} (W)	P_{ba} (W)	P_a (W)	P_o (W)	η (%)
Cathode grounded	20	3000	—170	400	300	150	15	50	4.5	450	125	325	72
Cathode grounded	60	2500	—170	400	300	170	15	50	4.5	425	125	300	70.5
Cathode grounded	100	2000	—150	400	280	170	15	50	6	340	120	220	65

the valves particularly suitable for transmitters working on wavelengths of a few metres, such as frequency-modulation and television transmitters. The good efficiency at these frequencies is directly due to the short transit time, low series-resistance of cathode, grid and anode connections, the low internal capacitances (ensuring a low current in the grid connection) and the very small quantity of materials employed in which dielectric losses occur.

At lower frequencies, too, these valves will give excellent service, e.g. in modulators and a.f. amplifiers.

Further details of frequency, voltages, current, powers and efficiencies for some of the more characteristic adjustments of the TB 2.5/300 and QB 2.5/250 are given in *tables I* and *II*; a list of the symbols employed is provided in *table III*.

Transmitting valves for higher powers

The principles outlined in the foregoing have also been followed in larger types of transmitting valves which are at the moment in an advanced stage of development.

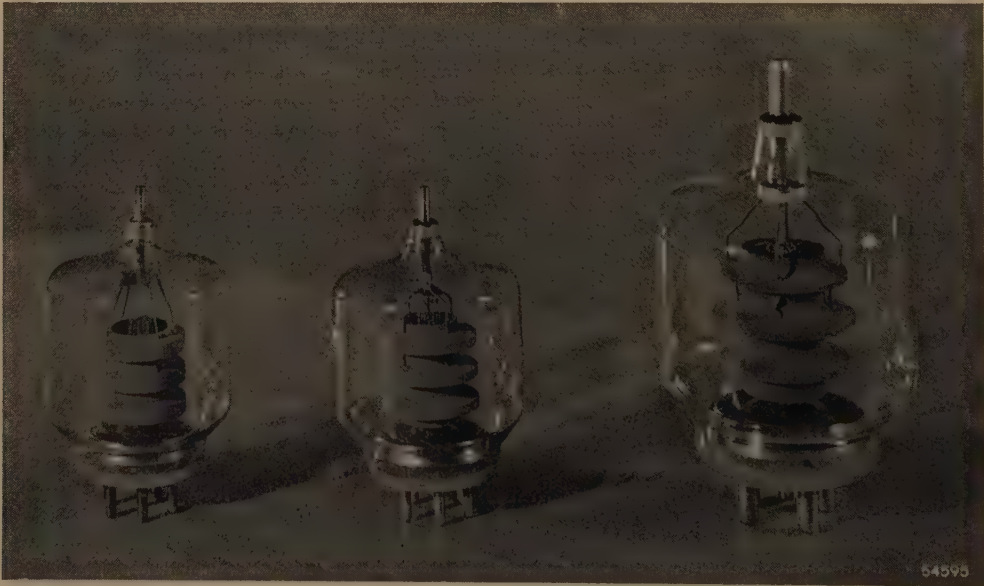


Fig. 14. Larger transmitting valves (still in development) based on the same lines as the TB 2.5/300 and QB 2.5/250. From left to right: tetrode with 250 W anode dissipation, triode with 270 W anode dissipation, triode with 540 W anode dissipation. Height of valves (incl. pins) about 147 and 205 mm (6'' and 8'') respectively.

Table III. Explanation of the symbols employed in tables I and II.

V_{ba}	=	D.C. anode voltage
V_{bg1}	=	D.C. control grid voltage
V_{bk}	=	D.C. cathode voltage
V_{bg2}	=	D.C. screen grid voltage
$V_{g1\max}$	=	peak alternating grid voltage
I_a	=	D.C. anode current
I_{g1}	=	D.C. control grid current
I_{g2}	=	D.C. screen grid current
P_{g1}	=	driving power
P_{ba}	=	D.C. input
P_a	=	anode dissipation
P_o	=	h.f. output
η	=	efficiency, defined as W_o/W_{ba} (the power to the filament, the control grid and the screen grid, if any, thus being disregarded).

Fig. 14 depicts two triodes designed for an anode dissipation of 270 W and 540 W, and a tetrode for 250 W.

The two smaller types are rated for 2 to 3 kV and

the larger one for 3 to 4 kV anode voltage, supplying an output of 500 to 800 W and 1200 to 1600 W respectively (Class C). Owing to the efficient internal screening and the low inter-electrode capacitances amongst other things, these ratings are obtainable at frequencies of 100 Mc/s and even higher.

As will be seen from *fig. 14*, the larger types are also manufactured according to the “all-glass” technique, with cylindrical electrode systems. In order to secure complete similarity throughout the whole range of valves, the design has been based on laws of conformity; the specific loading of the electrodes and envelope is therefore practically the same in all types, ensuring the same high degree of reliability.

The two smaller valves in *fig. 14* fit the same valve-holder as the TB 2.5/300 and QB 2.5/250; the larger one has pins of a different size but it nevertheless fits a current type of holder.



FORCING TULIPS WITH ARTIFICIAL LIGHT

by R. van der VEEN.

631.588.5

Tulips blooming in the early spring are usually forced in greenhouses, in daylight and at a temperature of about 20 °C. Experiments are now described showing that it is possible to obtain these early blooms by forcing the plants under artificial light in sheds insulated on all sides against any loss of warmth. The new method has several advantages, namely earlier blooms, better quality of both plant and flower, and reduced running expenses.

Forcing bulbs in greenhouses

Long before blossom time in the bulb-fields, tulips are on sale in flower shops, having been "forced" by a process in which warmth and light are the main factors.

Tulips which have appeared on the market in the early spring have so far always been forced in greenhouses: the grower sets his bulbs in the autumn, that is, towards the end of September or early October, placing them close together in "seed boxes", about 50 to a box. These boxes have to be kept in a fairly cool place, protected from frost; actually experience has shown that the best results, with slow growth, are obtained at a constant temperature of 9 °C. In practice it is usually considered sufficient to bury the boxes in the ground, as this has been found to provide the most satisfactory conditions for the development of the plant.

When the young plant is about 6 cm above the bulb (usually towards the end of December, or early January), the boxes are transferred to the greenhouse, where they are left in the daylight and at a temperature of some 21-22 °C. From that moment growth takes place very much more rapidly and, depending upon the particular sort of tulip, they will be in bloom within a period of 15 to 30 days. To obtain good results the two factors mentioned above must however be closely watched, viz. a temperature of slightly more than 20 °C, and sufficient daylight.

This, then, is a brief outline of the general method employed in growing early tulips. Needless to say, in times of fuel shortage it is rather a problem to maintain the greenhouses at the correct temperature, so much so that when there are periods of sharp frosts it is in many cases impossible, and as a result the early tulip crop fails.

The proper heating of greenhouses in very cold winters is rendered more difficult by the manner in which these greenhouses are usually built: generally they consist of a metal framework with glazed roof and sides and this is the main cause of dissipation of the heat within; most greenhouses are, in fact, a prolific source of fuel wastage. This great disadvantage

of the design, from the point of view of economy, is discounted, however, since light is an absolute necessity for the proper development of the plants.

Experimental forcing of tulips by artificial light

It is quite an obvious question, therefore, whether it would not be possible to force the bulbs in houses which are effectively insulated to prevent thermal losses and to provide the requisite amount of light by artificial means.

In general it might be said that the amount of light needed for the satisfactory growth of plants would be far too large to justify the exclusive use of artificial light from the economic point of view. On biological grounds there are no objections to this, but an illumination of about 2000 to 4000 lux would be involved for the greater part of each day and this would be considered costly.

The forcing of bulbs, however, is quite another matter. Sustenance for the proper development of the leaves and flower are already in reserve within the bulb, and light is not needed as a source of energy in the assimilation processes: it is concerned mainly with the form and direction of the growth. An important function of light is the production of chlorophyll. Furthermore a considerable quantity of light will have a retarding effect on the growth, thus preventing the plant from growing too tall and straggly. Blue light promotes the formation of anthocyanin in many plants, this being the substance that imparts a vivid red colour to the bloom.

In 1930, J. W. M. Roodenburg, in collaboration with Philips Laboratories, Eindhoven, carried out several experiments in the forcing of tulips by artificial light, but the results obtained at the time did not appear to justify experiments on a larger scale. In the spring of 1946, however, Roodenburg, J. D. W. van Geel and C. Schoutsen ¹⁾ once more took up the question of

¹⁾ Mededelingen van den Directeur van de Landbouw, 1948, p. 25.

forcing bulbs by artificial light and the results obtained, combined with the fuel shortage, induced van Geel to try this method on a larger scale. These trials, which yielded remarkable results, will now be reviewed in brief.

placed on the ledge. This installation represented about 90 W per square metre of illuminated area. The lamps were kept burning 9 hours a day. To get the most benefit from the light available the ceiling and walls of the shed were whitewashed.



Fig. 1. Tulips forced under incandescent lamps in a thermally insulated shed.

A gladiolus drying shed at Bovenkarspel was covered in on all sides with wood-fibre sheet ("Kramfors" board) to a thickness of an inch to provide effective thermal insulation, thereby shutting out all light. A stove, together with a ventilator, kept the temperature constant at 22 °C. The whole shed was fitted up with electric light: a wooden ledge about 110 cm in width was built along the whole length of the walls, with electric lamps of 75 W each mounted in rows above them, about 75 cm apart and at the same distance from the bulb boxes

The first batch of bulbs to be forced, of the "Krelage's Triumph" variety, showed exceptional development right from the start: the boxes of bulbs were placed in the shed on 18th December and the blooms began to appear 17 days later. For comparison a number of bulbs from the same lot were set in a greenhouse for forcing in the conventional manner. Not only was the quality of the tulips in the lighted drying shed definitely better, but the proportion of stragglers was very much smaller, being only 4% as against a normal 10 to

15%. The fact that these tulips were of better quality than those in the greenhouse is undoubtedly due to the better facilities for the control of light and heat in the shed, where the plants were not exposed to the vagaries of the weather.

January. Again the growth and quality were good, the blooms being superior to those of the plants forced in the greenhouse.

Following on these practical experiments we have conducted a number of further, smaller trials in



Fig. 2. A view of the drying shed at Bovenkarspel where large-scale experiments have been carried out in forcing tulips under artificial light.

The tulips grown in this way attracted very much attention in trade circles and experts pronounced them to be excellent. A striking feature was the great length of stem, combined with sufficient rigidity, this being a quality of considerable importance from the point of view of market value.

In view of the success obtained with "Krelage's Triumph", another batch of bulbs was put down, this time the much slower-growing "Bartigon" tulip, these being placed in the shed on 16th

collaboration with van Geel to ascertain whether less light might do or whether a different type of light might yield still better results. Some details of these experiments are given below.

The lighting employed in the main experiment, consisting of 75 W lamps (90 W per m²) for periods of 9 hours per day, proved to be just sufficient. A reduction in the power of the lamps to 40 W produced tulips of only fair quality; the colour of the leaf was too light and the blooms were on the

pale side, proving that the amount of light was inadequate to produce the essential chlorophyll in sufficiently large quantities. The shed was also lighted continuously, instead of only 9 hours a day, but in this case the growth was on the whole much too profuse, the leaf formation being so heavy as to produce difficulties in bunching. At the same time, the colour of both leaf and bloom was very good, as was also the length of stem. On an average, the flowers appeared some days before the others under 9 hours lighting per day.

Trials were also carried out with fluorescent lamps of different types, some of them giving mainly red or mainly blue light. With a power of 67 W per m² for 9 hours per day, the growth and quality of the tulips were excellent, but the general development was not quite so rapid as in the case of incandescent lamps, possibly because the fluorescent lamps give less infra-red radiation. The use of light sources of larger power, continuously alight, again resulted in a much more rapid growth, especially with red radiation.

It still remains to ascertain the optimum duration, intensity and colour of the lighting. It will then be possible to treat the various kinds of tulips differently in accordance with the particular characteristics most desired. Some types will be required to have a longer stem, while for other firmer stems, more leaf, or possibly a more vividly coloured flower may be desired. When the effect of artificial light upon the growth of the plant has been investigated more fully it should be possible to meet all these specific demands. The use of fluorescent lamps will be found preferable, since these offer a choice of either more red or more blue light. Experiments in that direction are now being conducted by the Agricultural Mechanisation Commission of North Holland, as well as in the Philips Laboratories at Eindhoven.

Saving in costs when artificial lighting is used

We have shown, then, that tulips forced under the light of incandescent electric lamps in thermally insulated sheds flower earlier and are of better quality than those forced in greenhouses.

The question whether this method will be universally adopted depends very largely on whether the running expenses are higher or lower than those of the old method. This point was investigated very carefully during the large-scale experiment at Bovenkarspel. It was found that the cost worked out as follows, per day and per square metre of bulb-box:

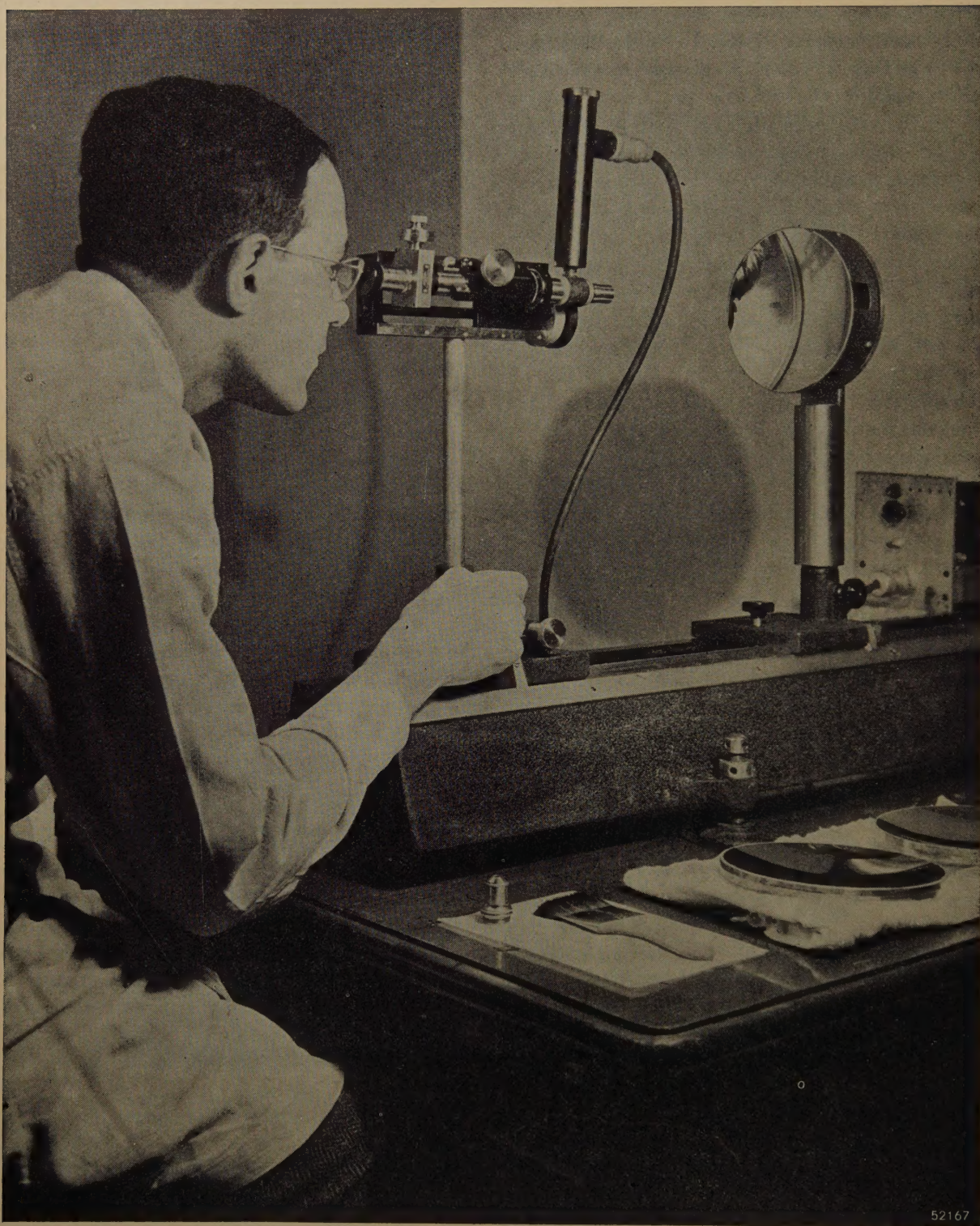
heating	f 0.011
electric current	f 0.024
lamps	f 0.009
total	f 0.044.

Against this, the cost of heating per m² of bulb-box in a greenhouse heated with oil fuel was found to be f 0.104 and in two other greenhouses heated with solid fuel f 0.051 and f 0.052. It must be remembered that these figures apply to the mild winter of 1947/48 and that in a very severe winter the cost of heating greenhouses is higher, whereas the costs for enclosed sheds remain almost the same, in which case the financial advantages of the new method are of even greater importance.

Apart from the saving on the fuel account, especially during a severe winter, a point in favour of incandescent lamps (or fluorescent lamps) is that the results will be more reliable and in many instances the construction and maintenance of special greenhouses will be unnecessary, seeing that existing sheds can be employed for the purpose.

Many growers in the Netherlands have already started converting their drying sheds for the forcing of tulips by artificial light, and this system is also receiving considerable interest in other countries.

EXAMINING MIRRORS FOR PROJECTION TELEVISION



52167

The quality of the concave spherical mirror of the Schmidt optical system used in projection television receivers ¹⁾ is examined with the aid of the apparatus shown in this picture (photo taken at Philips Laboratories, Inc., Irvington-on-Hudson,

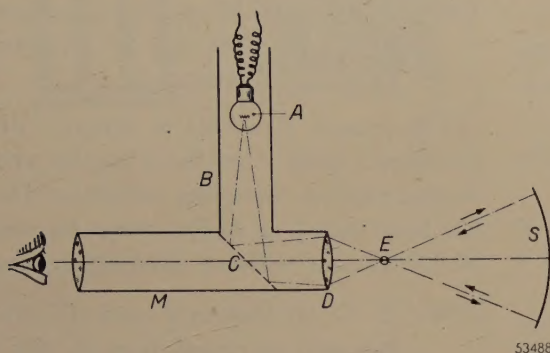
¹⁾ Cf. P. M. van Alphen and H. Rinia, Philips Techn. Rev. 10, 69-78, 1948/49 (no. 3).

N.Y., U.S.A.). The principle of the apparatus is explained with reference to the schematic sectional plan given here.

Light from a small intense source (e.g. a "concentrated arc lamp") mounted in the side tube *B* passes from a partially reflecting plate in the horizontal microscope tube *M* through the micros-

cope objective. The distance of the source from the partially reflecting plate being suitably chosen, a reduced image of the concentrated source is formed by the objective at point *E*, in the plane to which the combination of microscope objective and eye piece is permanently focused. This image (which cannot be seen through the microscope owing to the direction of the rays), serves as a point source

In order to avoid superposition of the inherent aberrations which would otherwise be produced even with an ideal spherical mirror, it is necessary for the light source (*E*) to be located at the center of the curvature of the mirror. The feature of the set-up described here is that this is done automatically when adjustments are made for obtaining the best possible focus of the image observed. These



- M* microscope tube
- B* side tube of microscope
- A* partially reflecting plate
- D* microscope objective
- E* position of real image of *A* projected through *D*
- S* spherical mirror being examined.

projecting a wide-angle light beam towards the spherical mirror. The image of this point source that is formed by the spherical mirror is viewed through the microscope in normal fashion, the only effect of the partially reflecting plate through which the rays must pass being a decrease in the brightness of the image. Any defects in the mirror are manifested through astigmatism, excessive spot size or non-uniform light distribution in the image observed.

adjustments consist in positioning the microscope to bring the image to the center of the field of vision, and varying its distance from the spherical mirror by means of a thumb screw. When the best focus is obtained the image must lie at point *E*, in the plane to which the microscope is permanently focused. The point source at *E* and the image of it that is formed by the spherical mirror and seen through the microscope therefore coincide, i.e., both lie at the center of curvature of the mirror

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk can be obtained free of charge upon application to the Administration of the Research Laboratory, Kastanjelaan, Eindhoven, Netherlands.

1790: H. Bremmer: On the propagation of radio waves around the earth (*Physica* 14, 301-318, 1948, No. 5).

Some questions about the propagation of radio waves around the earth are discussed. They concern successively:

- 1) an extension of Sommerfeld's q -formula, applicable to the curved earth,
- 2) a reduction of Maxwell's vector equations to a scalar wave equation in the case of a spherically symmetric medium,
- 3) the reduction of the field corresponding to orthodox tropospheric refraction to the field existing without refraction.
- 4) a geometric-optical derivation of the attenuation factor in Austin-Cohen's formula for long-wave propagation,
- 5) the sky-wave field near the antipode of the transmitter,
- 6) a discussion of the day-light absorption for short waves,
- 7) the course of the rays and the field of cosmic radio waves.

1791: N. G. de Bruijn: Logarithmic solutions of linear differential equations (*Phil. Mag.* (7) 39, 134-140, 1948, No. 2).

Starting from an expression given by Balth. van der Pol for $K_n(2\sqrt{x})$, where K_n is the Bessel function of the second kind, the author develops a method to derive similar expressions for "logarithmic" solutions of other 2nd order linear differential equations. Bessel's equation, Legendre's equation and the equation $xy'' + (1+x)y' - y = 0$ are given as examples. The last equation has as solution

$$\sum_{o}^{\infty} \frac{d}{dm} \left(\frac{x^m}{\Pi(m)} \right) = e^x \operatorname{li}(e^{-x}),$$

a result also derived by B. van der Pol with the aid of operational calculus.

1792: H. C. Hamaker: Toevalscijfers (*Statistica* 2, 97-106, 1948, No. 3). (Random sampling numbers; in Dutch.)

This paper describes a simple dice-throwing technique, using a ten-faced regular prism, for producing random sampling numbers. The technique has been tested in various ways on series of up to 40,000 throws without showing evidence of bias.

1793: H. B. G. Casimir and D. Polder: The influence of retardation on the London-Van der Waals forces (*Phys. Rev.* 73, 360-372, 1948, No. 4).

The influence of retardation on the energy of interaction between two neutral atoms is investigated by means of quantum electrodynamics. As a preliminary step, a discussion is given of the interaction between a neutral atom and a perfectly conducting plane, and it is found that the influence of retardation leads to a reduction of the interaction energy by a correction factor which decreases monotonically with increasing distance R . This factor is equal to unity for R small compared with the wavelengths corresponding to the atomic frequencies, and is proportional to R^{-1} for distances large compared with these wavelengths. In the latter case the total interaction energy is given by $-3hca/16\pi R^4$, where a is the static polarizability of the atom. Although the problem of the interaction of two atoms is much more difficult to handle mathematically, the results are very similar. Again the influence of retardation can be described by a monotonically decreasing correction factor which is equal to unity for small distances and proportional to R^{-1} for large distances. In the latter case the energy of interaction is found to be equal to $-23hc\alpha_1\alpha_2/8\pi R^7$.